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Sewage Research

STUDIES OF SEWAGE PURIFICATION

VIII. OBSERVATIONS ON THE EFFECT OF VARIATIONS IN THE INITIAL NUMBERS OF BACTERIA AND OF THE DISPERSION OF SLUDGE FLOCS ON THE COURSE OF OXIDATION OF ORGANIC MATERIAL BY BACTERIA IN PURE CULTURE *

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In earlier studies (1) of the fundamentals of the biochemical oxidation process, conducted with simple reproducible media and with pure cultures of bacteria, it was stated tentatively among other conclusions that:

1. Under natural conditions oxidation does not occur in the absence of living biological agents.
2. Oxidation takes place only as a result of the metabolic activity and proliferation of living bacteria, and is proportionate, though perhaps not directly, to the number of new cells produced.
3. The oxidation occurring during any time interval is proportional to the amount of food or organic material utilized by the bacteria.

This is the equivalent of saying that in a given set of such oxidations, carried on under standardized conditions, the initial course of the oxidation observed will be governed by the number of effective units of living bacterial protoplasm present at the start of each series of observations.

Under standardized conditions (namely with a simple reproducible medium, a constant temperature, an adequate supply of oxygen and a pure culture of bacteria) a definite, fixed amount of oxygen is required to oxidize the food material available to the bacterial species employed. Assuming a uniform generation time for the bacteria employed under the standardized conditions, it is reasonable to believe that the time required for this species of bacteria to oxidize all of the available food present (or to use up this fixed quantity of oxygen required) would vary with the number of individual units of bacteria present at the start of the test. That is, with large numbers of bacteria initially present the oxidation process should proceed much more rapidly than with a limited initial number, although the ultimate total oxygen requirement would be presumedly the same in both instances.

* Prepared for Presentation at the Joint Meeting of the New York and New England Sewage Works Associations, October 6, 7, 8, 1938, at Hartford, Conn.

Under such conditions, if the time intervals between determinations were too long, the results obtained would reveal the approach to the total oxygen requirement but would not reveal in any sense the course of oxidation followed in arriving at the observed point. Observations essential for the determination of the course of oxidation during this critical phase of the reaction would be missed and, moreover, due to the usual method of presenting results in the form of a cumulative curve, rather than by differences, any irregularities at the beginning of the curve would be concealed. Consequently any opportunity to observe the effect of an increased initial number of bacteria, should the condition exist, would be lost.

In the studies referred to (1) the time interval between determinations was 24 hours and the time required for the satisfaction of the total oxygen requirement varied from 24 to 72 hours. Consequently no conclusions can be drawn regarding the course of oxidation during the first 24-hour period. Experiments have been completed with the initial concentrations of bacteria intentionally varied within wide limits by two different methods and with the time intervals between examinations so shortened that frequent determinations were made during the critical stage of the reaction. The procedure following in setting up and conducting these experiments and the results obtained will now be presented.

I. Effects of Initial Bacterial Populations on Growth Rates and Resultant Oxidations

A. Initial Population Varied by Multiple Increases in the Volume of the Inoculum

Preparation.—Five 8-liter pyrex serum bottles, designated A, B, C, D and E, each containing 0.09 g. dextrose, 0.09 g. peptone and 0.09 g. dipotassium phosphate in 6 liters of formula "C" dilution water (2) were sterilized by autoclaving. After sterilization any loss in weight incurred was restored by the addition of sterile distilled water. Additional materials, B.O.D. bottles, pipettes, graduates, siphons, etc., required for the set-up, appropriately protected from subsequent contamination by cotton filters, paper caps, etc., were sterilized in the same manner. All bottles were stored at 20° C., to check their sterility and to standardize their temperature. The culture of *Bact. aerogenes,* laboratory strain No. 72, to be used in the test was rejuvenated through a series of transfers and put on an agar slope for 40 hours incubation at 20° C. prior to the start of the test.

Procedure.—The growth from the agar slope of *Bact. aerogenes* was washed off and placed in 100 ml. of sterile dilution water. Ten ml. of this bacterial suspension were put in Bottle A and incubation at 20° C. was continued. (This 10 ml. seeding produced in the 6 liters of Bottle A a bacterial content of about 100,000 per ml.) After 40 hours storage at 20° C. (at the end of this period the growth of *Bact. aerogenes* was approaching its maximum), Bottle A was removed from the incu-

bator and after thorough mixing of its contents, 4 liters were transferred by sterile siphon to a clean, sterile pyrex flask, marked AX. The temperature of the flask, AX, (and contents) was raised to boiling and then held at 90° C. or higher for 20 minutes. It was then cooled to 18–20° C., and thoroughly agitated. This treatment was sufficient to kill all *Bact. aerogenes* and to destroy any known enzyme. After thorough mixing, additions to Bottles B, C, D and E from the contents of the original Bottle A and flask AX, were made in order as follows:

	B	*C*	*D*	*E*
Ml. from A	1	10	100	1000
Ml. from AX	999	990	900	0

This procedure provided conditions for the organic contents of the 4 bottles, B, C, D and E, to be identical with the possible exception of a minor variation due to the partial loss of some of the volatile constituents from the portions of heated material added. Provision was also made for decimal increases between each bottle in their content of living units of bacterial protoplasm. That is, if Bottle B had 1 bacterium per ml., C would have 10, D 100 and E 1000 per ml. The additions from A and AX were made in order and as soon as the increments to one bottle had been completed its contents were thoroughly mixed, aerated and transferred through a sterile siphon to sterile B.O.D. bottles (300 ml. ground glass stoppered, biochemical oxygen demand bottles). This was continued until the contents of all large bottles had been transferred to B.O.D. bottles. As each set was completed the time was noted and two bottles were examined for their bacterial and dissolved oxygen contents. The remainder of the bottles were stored at 20° C. Thereafter at frequent intervals, as indicated in the tables of results, bottles were removed from the incubator and examined.

Dissolved oxygen determinations were made by the Standard (3) Winkler method. Prior to the addition of the Winkler reagents the contents of the B.O.D. bottle or bottles to be tested were carefully but thoroughly mixed, without aeration, and one ml. was withdrawn for bacteriological examination. Bacterial counts were made by plating on standard agar. To increase accuracy, dilutions were adjusted so that it was not necessary to measure volumes of less than one ml. and a sufficient number of plates at each dilution were poured to provide for 3 plates at the dilution selected for counting. The counts from these 3 plates were averaged for the reported result. The dilutions required to obtain plates with the number of colonies at the counting level could be judged very closely from the amount of oxygen utilized in the bottle under test. This amount of oxygen could be determined quickly and experience with this type of reaction permitted a close estimate of the probable numbers of bacteria present.

Results.—The observed oxygen requirements are presented in Table I and are shown graphically in Fig. 1. The results for series B for the period from the 16th to the 22nd hour (1:00 A.M. to 7:00 A.M. when observations were not made) were calculated from a curve based on the observed results for the series with the section of the curve for the 15th to the 23rd hour interpolated in accordance with the trends

TABLE I.—*Oxygen Utilized by Bact. Aerogenes During Growth in Pure Culture in Dilute Medium at 20° C. when the Initial Bacterial Content was Varied. Results are Expressed in Mgs. of O_2 per Liter*

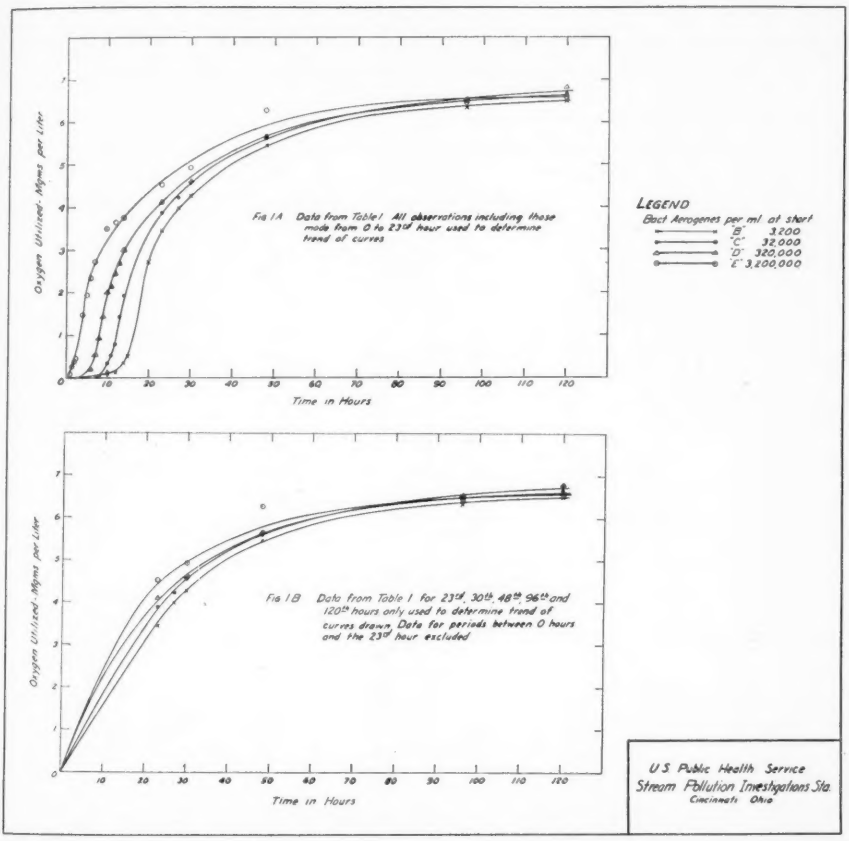
Series Designation and Number of Bacteria Per Ml. in Each Series at the Start							
B. 3,200		*C.* 32,000		*D.* 320,000		*E.* 3,200,000	
Time Hours	Mgs. O_2	Time Hours	Mgs. O_2	Time Hours	Mgs. O_2	Time Hours	Mgs. O_2
2.0	0.00	0.5	0.00	0.25	0.00	0.25	0.00
4.5	0.00	1.0	0.00	0.5	0.00	0.5	0.00
6.0	0.00	2.5	0.00	1.0	0.00	0.75	0.03
8.0	0.00	4.0	0.00	1.5	0.00	1.0	0.08
10.0	0.10	6.0	0.00	2.5	0.00	1.5	0.25
12.0	0.11	8.0	0.01	4.0	0.00	2.0	0.36
14.0	0.34	10.0	0.34	6.0	0.18	2.5	0.45
15.0	0.49	11.0	0.52	7.0	0.54	4.0	1.49
16.0*	0.90*	12.0	0.78	8.0	0.93	5.0	1.93
18.0*	1.95*	13.0	1.41	9.0	1.42	6.0	2.34
20.0*	2.70*	14.0	1.92	10.0	2.00	7.0	2.71
22.0*	3.26*	23.0	3.88	11.0	2.14	10.0	3.50
23.0	3.45	27.0	4.22	12.0	2.43	12.0	3.66
27.0	3.99			13.0	2.68	14.0	3.74
				14.0	2.99	23.0	4.54
				23.0	4.11		
30.0	4.26	30.0	4.56	30.0	4.60	30.0	4.93
48.0	5.45	48.0	5.64	48.0	5.63	48.0	6.28
96.0	6.34	96.0	6.37	96.0	6.50	96.0	6.45
120.0	6.50	120.0	6.68	120.0	6.80	120.0	6.59

* Results for these periods, covering the early morning hours, were estimated from a theoretical curve based on trends of results in *C*, *D* and *E* and made with the data for Series *B* of the 10th, 11th, 12th, 14th, 15th and 23rd, and subsequent hours employed to allocate the curve.

indicated for similar periods in series C, D and E. All other recorded results represent actual observations.

In Fig. 1 two sets of curves have been drawn. In 1-*a* all observed points are included in determining the shape of the curves. In 1-*b* all points obtained prior to the 23rd hour have been omitted in establishing the trend of the curves. This is done to provide for a comparison be-

tween the results obtained by the usual procedure, when observations are not made until the end of 24 hours of storage, and by the procedure followed here. If the curves be based on the results for the 48, 96 and 120th hours, which is done more frequently in routine practice, then the curves for B, C, D and E would be practically identical. As actually observed, measurable oxygen utilization occurred in E at the end of the first hour, in D at the end of the sixth hour, in C at about the


Oxygen Utilized - Mgms per Liter
Time in Hours
Fig 1A Data from Table I All observations including those made from 0 to 23rd hour used to determine trend of curves
LEGEND
Bact Aerogenes per ml at start
'B' 3200
'C' 32,000
'D' 320,000
'E' 3,200,000
Fig 1B Data from Table I for 23rd, 30th, 48th, 96th and 120th hours only used to determine trend of curves drawn. Data for periods between 0 hours and the 23rd hour excluded
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Cincinnati Ohio

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FIG. 1, *a* AND *b*.—Oxygen utilization by *Bact. aerogenes* at 20° C., with varying numbers of bacteria present at the start, when frequent determinations are made during the first 24 hours and when no determinations are made until the 23rd hour.

ninth hour, and in B not until the twelfth hour. However, at the end of 30 hours from the start of the experiment, when observed oxidation had been taking place in B, C, D and E for 18, 21, 24 and 29 hours respectively, the amounts of oxygen utilized in B, C and D in order represented 86, 92 and 93 per cent of the amount utilized in E, while at the 96 and 120th hours, the results for all bottles are well within the limit of error of such determinations, being namely 98, 99 and 101, and

99, 101 and 103 per cent respectively, for these periods, of the amount of oxygen used in E.

Thus from the results of these tests if the 5-day biochemical oxygen demand were the only point of interest in the determination it would be immaterial whether the initial bacterial content was 3,000 or 3,000,000 per ml., the final result would be the same. However, if the amount of oxidation occurring during the first few hours of the test were desired, the initial density of the bacterial population would be of major im-

TABLE II.—*Hourly Rates of Oxygen Utilization by Bact. Aerogenes Growing in Pure Culture in Dilute Medium at 20° C. when the Initial Bacterial Content was Varied. Results Expressed in Mgs. of O_2 per Liter*

Series Designation and Number of Bacteria Per Ml. in Each Series at the Start							
B. 3,200		*C.* 32,000		*D.* 320,000		*E.* 3,200,000	
Hours Time *	O_2 Used *	Hours Time *	O_2 Used *	Hours Time *	O_2 Used *	Hours Time *	O_2 Used *
2.0	0.00	0.5	0.00	0.25	0.00	0.25	0.00
4.5	0.00	1.0	0.00	0.5	0.00	0.5	0.00
6.0	0.00	2.5	0.00	1.0	0.00	0.75	0.12
8.0	0.00	4.0	0.00	1.5	0.00	1.0	0.20
10.0	0.05	6.0	0.00	2.5	0.00	1.5	0.34
12.0	0.01	8.0	0.01	4.0	0.00	2.0	0.22
14.0	0.12	10.0	0.16	6.0	0.09	2.5	0.18
15.0	0.15	11.0	0.18	7.0	0.36	4.0	0.69
16.0†	0.41†	12.0	0.26	8.0	0.39	5.0	0.44
18.0†	0.52†	13.0	0.63	9.0	0.49	6.0	0.41
20.0†	0.38†	14.0	0.51	10.0	0.58	7.0	0.37
22.0†	0.28†	23.0	0.22	11.0	0.14	10.0	0.26
23.0	0.19	27.0	0.08	12.0	0.29	12.0	0.08
27.0	0.13			13.0	0.25	14.0	0.04
				14.0	0.31	23.0	0.09
				23.0	0.12		
30.0	0.09	30.0	0.11	30.0	0.07	30.0	0.06
48.0	0.07	48.0	0.06	48.0	0.06	48.0	0.08−
96.0	0.02	96.0	0.01	96.0	0.02	96.0	0.00+3
120.0	0.01	120.0	0.01	120.0	0.01	120.0	0.00+5

* Results are expressed in terms of mgs. of O_2 per liter used per hour during the time period covered. The time period covered in each instance is the interval between the hour given for result recorded and the hour of the preceding examination.

† Results for these periods based on estimated results, cf. Footnote Table 1.

portance for in E, with the highest numbers of bacteria, at the end of 6 hours 41 per cent of the 5-day oxygen requirement had been satisfied, in D, at the same period, with one-tenth as many bacteria at the start, oxidation had just started (2½ per cent of the 5-day requirement) while in C and B a measurable loss of oxygen was not observed until from 3 to 6 hours later.

A more detailed presentation of the influence of the initial bacterial concentration on the course of oxidation during the early hours of

storage (first 24 hours) is made in Table II and Fig. 2. The data of Table II were obtained by calculation from the results given in Table I, by deducting the amount of oxygen utilized at each period of observation from the amount of each following observation and expressing this difference in terms of hourly rates of oxidation for the interval involved. To illustrate, in series E the difference between the oxygen requirements for the 2.5 and 2.0 hour periods was 0.09 mgs. of oxygen per liter $(0.45 - 0.36 = 0.09)$, and as the interval covered was 0.5 of

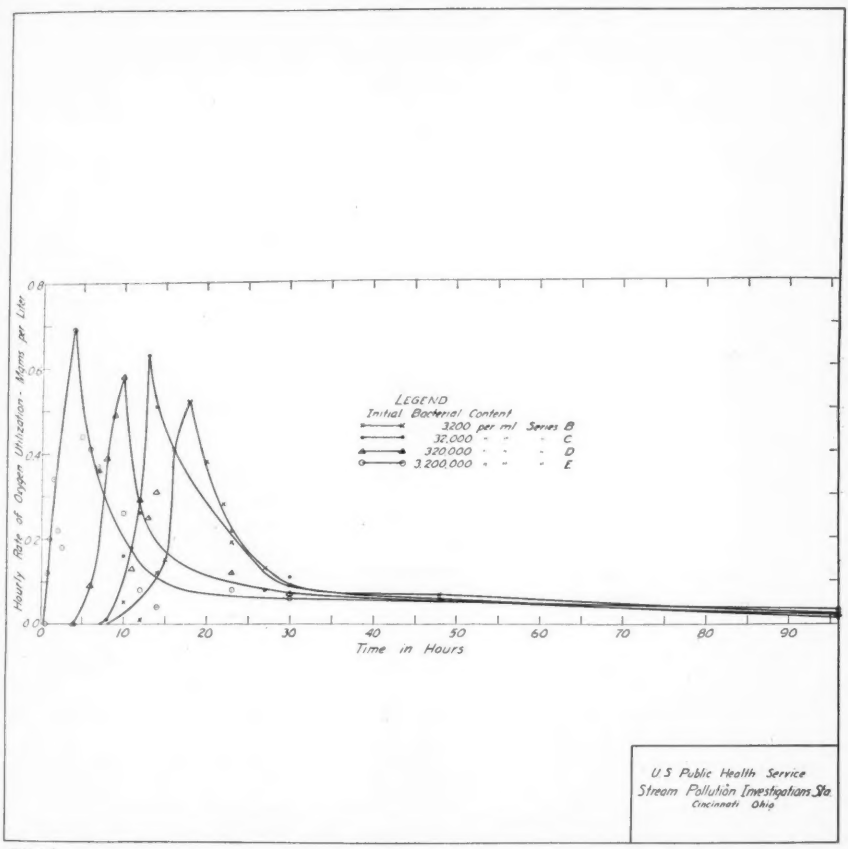

Fig. 2.—Hourly rates of oxygen utilization by *Bact. aerogenes* at 20° C., when the numbers of bacteria present at the start were varied.

an hour, the indicated hourly rate was 0.18 mgs. oxygen per liter $(2 \times 0.09 = 0.18)$. Or in the same series the difference between the 4.0 hour and 2.5 hour requirement was 1.04 $(1.49 - .45 = 1.04)$ mgs. of oxygen per liter and as the period covered was 1.5 hours the hourly rate for this interval was 0.69 $(1.04 \div 1.5 = 0.69)$.

An inspection of these data as given in Table II and illustrated in Figure 2 discloses some interesting facts which are not readily discerni-

ble from Table I and Fig. 1, where cumulative results rather than differences are considered. It is noted that, regardless of the number of bacteria present at the start of a test, the hourly rate of oxidation increased to a well defined maximum and thereafter decreased rapidly until by the 30th hour a low rate prevailed in all four of the series. Thereafter this low rate continued to decrease very gradually to the end of the series of observations. However, when the time at which the maximum rate occurred is considered, it is observed that the numbers of bacteria present at the start exerted a very marked effect. For

TABLE III.—*Numbers of Bact. Aerogenes Developing in Dilute Medium at 20° C. when the Initial Numbers were Varied Within Wide Limits*

Storage time in hours	Series Designation			
	B	*C*	*D*	*E*
0.0	3,200	32,000	320,000	3,200,000
0.25			306,000	2,340,000
0.5			300,000	
1.0			320,000	
1.5			200,000	
2.0	3,000			1,840,000
2.5		25,600	250,000	2,360,000
4.0		26,000	440,000	4,660,000
4.5	3,000			
5.0				6,940,000
6.0	7,000	50,000	600,000	5,760,000
7.0			1,360,000	9,900,000
8.0	20,600	216,000	1,960,000	
9.0			3,160,000	
10.0	100,000	600,000	4,740,000	13,600,000
11.0		1,150,000	8,060,000	
12.0	296,000	1,860,000	7,500,000	13,000,000
13.0		3,600,000	10,000,000	
14.0	704,000	4,540,000	12,000,000	17,800,000
15.0	1,460,000			
23.0	12,400,000	16,400,000	15,800,000	18,000,000
27.0	14,900,000	17,400,000		
30.0	17,100,000	16,400,000	16,800,000	21,600,000
48.0	20,800,000	18,100,000	20,200,000	16,400,000
96.0	17,700,000	18,300,000	15,400,000	19,600,000
120.0	18,400,000	18,600,000	18,200,000	18,200,000

instance, in Series E (initial bacterial content 3,200,000 per ml.) the maximum rate was observed at or possibly just prior to the 4th hour; in Series D, C and B (with initial bacterial contents, in order, of 320,000, 32,000 and 3,200 per ml.) the maximum hourly rates were observed respectively at the 10th, the 13th (or possibly between the 13th and 14th hours) and the 18th hours of storage. Thus it is shown that although the initial bacterial concentration had no effect on the final oxidation results obtained, it did have a very marked effect on the time

of occurrence of the maximum rate of oxidation and consequently on the amount of oxygen required during the early hours of a test.

The results of the bacteriological examinations are presented in Table III and Fig. 3. While it would be interesting to correlate oxygen requirements for given intervals of time with the number of bacteria present, or rather with the number of new cells produced during the same interval, this attempt cannot be made effectively with the avail-

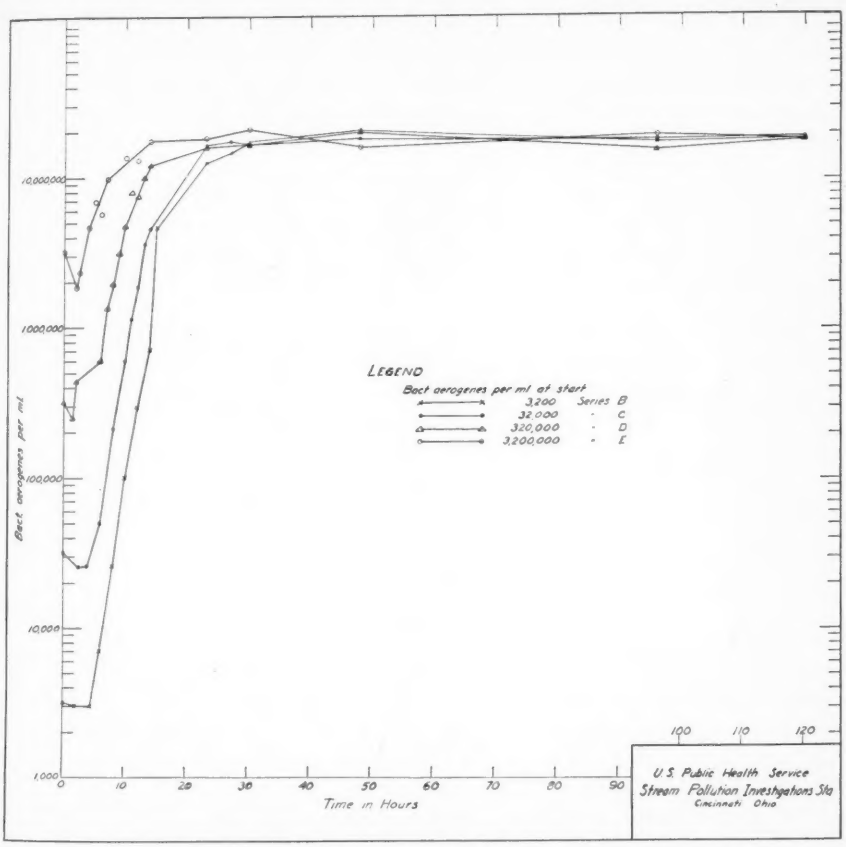

FIG. 3.—Numbers of *Bact. aerogenes* developing at 20° C., in identical media when the numbers of bacteria present at the start were varied.

able methods of bacterial enumeration. For in bacterial growth and multiplication, the cell absorbs food material and, as it grows, oxidizes part of this food and synthesizes part into increased cellular material. When the increase in cell volume is sufficient to activate cell division, a constriction appears about the middle of the cell and continues to increase until division is complete. Then two cells are present where there was formerly only one. Until the time when this cell division is completed (regardless of the absorption or oxidation caused by cell

growth) plate counts would indicate the presence of only one cell. Consequently the increase in bacterial numbers as indicated by plate counts would continuously lag behind the time of actual food utilization.

Thus in Series D, for the period from the 8th to the 10th hour, the indicated number of new cells per ml. required to utilize 1.0 mg. of oxygen per liter was 2,600,000, while for the succeeding 2-hour period 6,400,000 cells per ml. apparently were required for the same utilization.

It is interesting to observe that for Series C, during the period from the 12th to the 14th hour, and Series E, for the period of the 2nd to the 4th hours (periods of activity similar to the 8th to the 10th hours in D) the indicated number of new cells required per ml. to produce an oxygen requirement of 1.0 mg. per liter was 2,350,000 and 2,500,000 respectively. This is in remarkable agreement with the indicated number of bacteria required in Series D.

Certain trends indicated by the bacterial results also may be noted. First, a lag period was observed in all four series; in Series B and C it prevailed for about four hours, while in D and E its duration was for only two hours; thereafter active multiplication occurred in all series.

As the oxygen requirement per bacterial cell is exceedingly small (100,000 to 500,000 cells per ml., are required to produce a measurable oxygen requirement of 0.1 mg. per liter), it was to be expected that oxygen losses would be observed, first, in the series containing the largest numbers of bacteria at the start, and last, in the series containing the fewest at the start. As a matter of fact the bacteria in B did not reach the number present at the start in C until about the 8th hour; those in C did not match the initial concentration in D until about the 9th hour; while the numbers in E at the start were equalled by those in D at about the 8th hour. Stated in another way, the bacteria in E had increased from 3,000,000 per ml. to about 13,000,000 per ml. in 10 hours, a four-fold increase at a level that required 3.5 mgs. of oxygen per liter, while in B during the same 10-hour interval, although a thirty-three-fold increase had occurred (3,000 to 100,000 bacteria per ml.), the bacterial population had only just reached a concentration where measurable reductions, 0.1 mg. of oxygen per liter, might be expected. However, after 23 to 30 hours of incubation, and thereafter, the bacterial populations in all four series were practically identical. Thus it is noted again that if the 3-, or the 5-day bacterial populations were the only points of interest it would be immaterial whether the initial bacterial population was 3,000 or 3,000,000 per ml., the result would be the same; but if the population concentration during the first few hours, or the oxygen requirements for the same period, were the desired factors, then the initial population would be of major importance.

B. Initial Population Acting on Substrate Varied by the Introduction of Food Increments

Experiments in which measured increments of food (organic material) were introduced after the resulting successive increases in bac-

terial numbers had occurred will now be considered. In general the same preparation and methods were followed in this series of experiments as has been described above. Certain deviations, made in this series, from the described routine are noted as follows: The bacterial food employed was composed of exactly the same constituents but their concentrations were reduced so that each liter of standard medium contained 0.01 gram dextrose, 0.01 gram peptone and 0.01 gram phosphates. This reduction in concentration from 0.015 gram to 0.01 gram per liter was made because the cumulative effects of successive increments of food would increase the residual requirement for oxygen with consequent dangers of depletion. For these experiments the food was prepared in sterile concentrated solution of such a strength that 2 ml. added to one liter of dilution water prepared a standard medium of the given concentration. The food was prepared in this form to provide conditions for successive additions of exactly duplicate portions of food without any material alteration in the volume of the medium.

The *Bact. aerogenes* culture used for this series of experiments was laboratory strain No. 2. This strain has been in use in the laboratory for over 15 years and while it has retained all of its original biochemical characteristics it has changed apparently from an "S" to an "R" type. As an "R" type it exhibits a decided tendency to form small loose flocs or clumps which settle out. (Effect of removing part of bacterial population.) This phenomenon was not exhibited by this strain originally, nor by laboratory culture No. 72 used in the preceding experiments. This tendency to floc places this organism, as far as clumping is concerned, in an intermediate position between laboratory strain No. 72 and zoogleal bacteria which form rather large and tenacious flocs. It was for this reason that culture No. 2 was used in this series of tests.

Procedure.—In this series five pyrex carboys, designated A, B, C, D and E, containing identical kinds and amounts of dilution water, were prepared and sterilized by autoclaving. Subsequent to sterilization each carboy was stored at 20° C. for adjustment of temperature and sterility tests. The contents of each carboy were adjusted by weight, if made necessary by evaporation losses, to their original quantity by the addition of sterile distilled water. To each carboy was then added 2.0 ml. of the concentrated medium per liter, and also exactly the same amount of the same suspension of *Bact. aerogenes.* After thorough mixing and aeration, the contents of carboy A were immediately transferred by sterile siphon to sterile B.O.D. bottles. These bottles, together with carboys B, C, D and E, were stored at 20° C. Frequent examinations, for bacterial numbers, dissolved oxygen content and hydrogen-ion concentration, were made on the contents of the bottles of A.

At the 23-hour storage period carboys B, C, D and E were re-fed with the concentrated medium at the rate of 2.0 ml. per liter. After thorough mixing and aerating the contents of carboy B were trans-

ferred to sterile B.O.D. bottles. Storage at 20° C. was continued throughout. Frequent examinations, as with the A bottles, were made of the B bottles and the examinations of bottles from the A series were continued. (Thus the changes occurring in the A bottles after the 23rd hour could be used as a control, or correction, for the changes observed in the B bottles so that the results from each series of bottles could be attributed to the effect of the presence of one increment of concentrated medium, i.e., concentrated medium 2 ml. per liter.)

At the end of a further 23 hours of storage, namely 46 hours from the start of the test, carboys C, D and E were fed again with concentrated medium at the rate of 2.0 ml. per liter, the contents were thoroughly mixed and aerated, sterile B.O.D. bottles were filled from the contents of carboy C and storage and examinations were continued.

After 4 more hours of storage (4 hours from the time the contents of carboy C had been put in B.O.D. bottles, 50 hours from the start of the test) carboys D and E were fed again at the same rate with the concentrated medium and sterile B.O.D. bottles were filled from the contents of carboy D after thorough mixing. After a further storage period of 21 hours (*i.e.* 21 hours from the time the D bottles were filled, 71 hours from the start of the test) carboy E was given its final feeding at the same rate with the concentrated medium and its contents were transferred to sterile B.O.D. bottles. Storage and examinations were continued throughout as cited above. In addition, ten or more colonies were picked from the plates made for bacterial counts of the initial and final bottles of each series, and identified to check on the possible presence of any contamination.

Results.—No evidence was obtained at any time indicating that the bottles had become contaminated with other species of bacteria. The hydrogen ion concentration of the diluted medium remained at pH 7.1 throughout the period of examinations. These data have been omitted from the tabulations.

The oxygen requirements for each series of this experiment are recorded in Table IV as observed, without correction, in terms of milligrams of oxygen used per liter of medium.

To express the results on a comparable basis (*i.e.* in terms of the oxygen utilized for one increment of food in each series) it was necessary to correct the results of series B, C, D and E for the residual oxygen requirement in each at the time the new increment of food had been added. Thus the B results were corrected by the amount of oxygen used in the A series during the period of examinations of B; the results from the C bottles were corrected by the amount of oxygen used in the B bottles during the interval that C bottles were being examined, and so on. In the case of the results from Series E bottles this correction could not be made as the D bottles became depleted of oxygen at the time the examination of Series E bottles was started. Consequently, the results for the E Series are undoubtedly too high, the error probably ranging from at least 0.04 mg. for the first 0.5-hour period to, at least, as much as 0.5 to 0.6 mg. at the 7- to the 24-hour

periods. The amount of these corrections for the intermediate intervals was determined by carefully plotting the results, for each two series concerned in each case, in large scale and selecting these corrections from the proper points on these curves. These corrected results are given in Table V and are graphically shown in Figure 4.

TABLE IV.—*Oxygen Utilization by Bact. Aerogenes Growing in Dilute Medium in Pure Culture Recorded as Observed for Series A, B, C, D and E when Refed with Same Amount of Food at the 23, 46, 50 and 71-Hour of Storage at 20° C. (These Data are Presented Again in Table 5, Corrected, for Residual Oxygen Requirement of Preceding Food Additions. Results are Expressed in Mgs. O_2 per Liter*

Series A		Series B		Series C		Series D		Series E	
Time in Hours	Mgs. O_2	Time * in Hours	Mgs. O_2	Time * in Hours	Mgs. O_2	Time * in Hours	Mgs. O_2	Time * in Hours	Mgs. O_2
0.5	0.00	0.5	0.53	0.25	0.45	0.08	0.28	0.12	0.33
1.0	0.05	1.0	0.98	0.5	0.79	0.25	0.98	0.25	0.96
1.5	0.03	1.5	1.44	0.75	1.10	0.50	1.38	0.5	1.56
2.0	0.01	2.0	1.80	1.0	1.39	0.75	1.83	0.75	2.05
2.5	0.03	2.5	2.25	1.5	1.97	1.0	2.33	1.0	2.44
3.0	0.07	3.0	2.68	2.0	2.45	1.5	2.89	1.5	3.08
3.5	0.07	3.5	2.94	2.5	2.80	2.0	3.38	2.0	3.41
4.5	0.07	4.5	3.34	3.0	3.09	2.5	3.68	2.5	3.65
5.0	0.13	5.0	3.49	3.5	3.27	3.0	3.86	3.0	3.97
5.5	0.21	6.0	3.81	4.0	3.41	3.5	4.03	3.5	4.22
6.0	0.24	7.0	4.14	5.0	3.79	4.0	4.36	4.5	4.79
6.5	0.26	23.0	5.19	6.0	4.11	5.0	4.68	5.5	5.13
7.0	0.38	26.0	5.27	7.0	4.36	21.0	8.08+	7.0	5.82
9.0	1.06	31.0	5.47	9.0	4.86			25.0	7.79+
10.0	1.50	48.0	5.74	25.0	5.63				
11.0	2.19			50.0	6.17				
12.0	2.84								
13.0	3.25								
13.5	3.43								
23.0	4.39								
30.0	4.74								
46.0	4.82								
54.0	4.98								
71.0	5.16								
96.0	5.01								
120.0	5.14								

* Hours from time of each addition of food. Data in subsequent tables for Series A are set back 4.5 hours to allow for initial lag in growth.

Hourly rates of oxygen utilization for series A, B, C, D and E have been calculated from the results given in Table V. These calculated figures were obtained, as in the first experiment, by deducting the amount of oxygen utilized at each period of observation from the amount of each following observation and then expressing the difference in hourly amounts of oxidation for the time period ended by the last

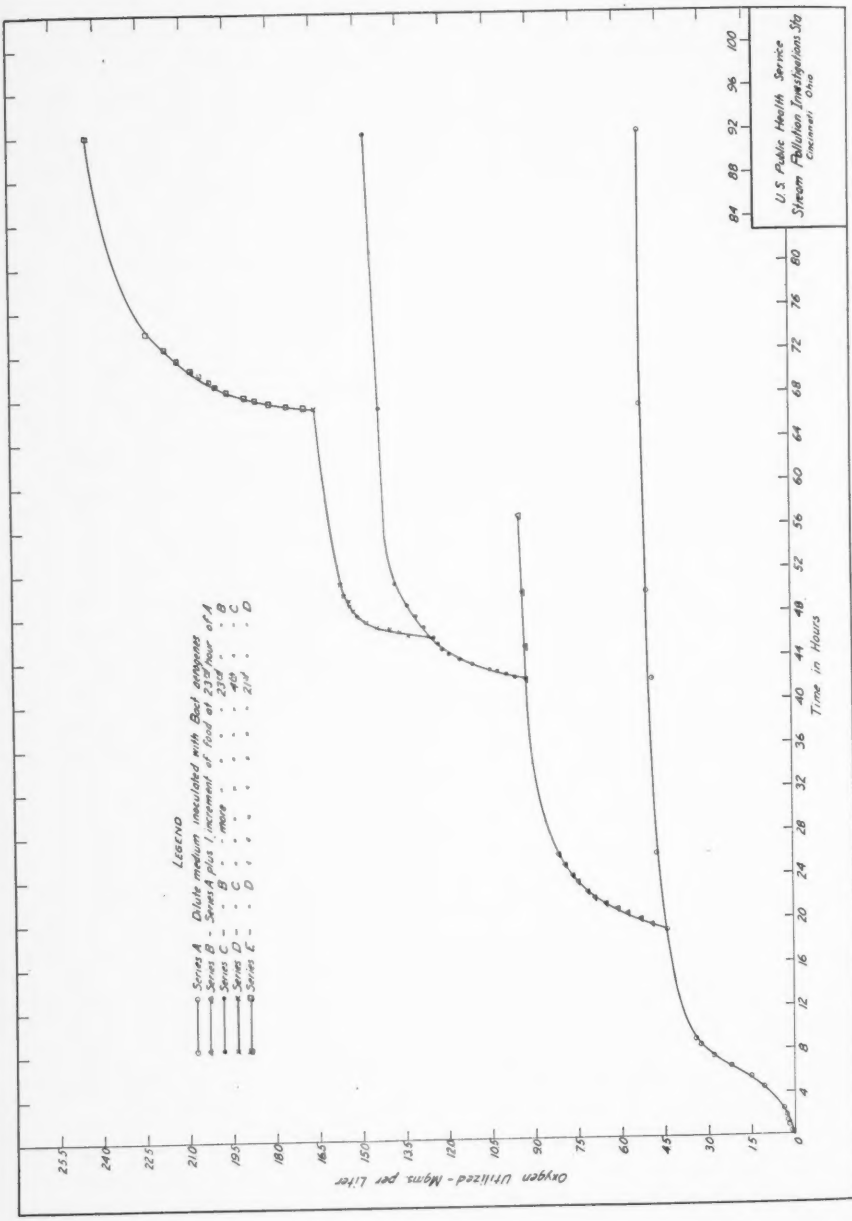
Legend
Series A - Dilute medium inoculated with Bact aerogenes
Series B - Series A plus 1 increment of food at 23rd hour of A
Series C - " B " " " " 23rd " " B
Series D - " C " " " " 48 " " C
Series E - " D " " " " 21st " " D
Oxygen Utilized - Mgms. per Liter
Time in Hours
U.S. Public Health Service
Stream Pollution Investigations Sta
Cincinnati, Ohio

FIG. 4.—Oxygen utilized by *Bact. aerogenes* at 20°C., when refed at various intervals with identical portions of the same medium. Data corrected for residual O_2 requirements of preceding food.

of the two observations under consideration. Essentially this consists in reporting the results in the form of the amount of oxygen used during each interval rather than in the form of accumulated amounts of oxygen utilized since the start of the test. This method of presentation permits a ready determination of the rates of oxidation from hour to hour when subjected to the varying conditions provided in this experiment. These hourly rate results are presented in Table VI and in Fig. 5.

TABLE V.—*Oxygen Utilization Results of Table IV Corrected in the Case of Series B, C and D for the Residual Oxygen Requirement Remaining from Preceding Food Increments. Results are Expressed in Mgs. of O_2 per Liter and are Plotted in Fig. 4*

Series A *		Series B		Series C		Series D		Series E ‡	
Time in Hours	Mgs. O_2	Time † in Hours	Mgs. O_2	Time † in Hours	Mgs. O_2	Time † in Hours	Mgs. O_2	Time † in Hours	Mgs. O_2
0.5	0.13	0.5	0.51	0.25	0.41	0.08	0.24	0.12	0.33
1.0	0.21	1.0	0.92	0.5	0.74	0.25	0.88	0.25	0.96
1.5	0.24	1.5	1.36	0.75	1.04	0.50	1.18	0.5	1.56
2.0	0.26	2.0	1.68	1.0	1.32	0.75	1.55	0.75	2.05
2.5	0.38	2.5	2.10	1.5	1.89	1.0	1.96	1.0	2.44
4.5	1.06	3.0	2.50	2.0	2.36	1.5	2.35	1.5	3.08
5.5	1.50	3.5	2.74	2.5	2.70	2.0	2.66	2.0	3.41
6.5	2.19	4.5	3.09	3.0	2.97	2.5	2.79	2.5	3.65
7.5	2.84	5.0	3.22	3.5	3.13	3.0	2.89	3.0	3.97
8.5	3.25	6.0	3.50	4.0	3.25	3.5	2.93	3.5	4.22
9.0	3.43	7.0	3.78	5.0	3.60	4.0	3.13	4.5	4.79
18.5	4.39	23.0	4.76	6.0	3.89	5.0	3.22	5.5	5.13
25.5	4.74	26.0	4.77	7.0	4.11	21.0	4.08	7.0	5.82
41.5	4.82	31.0	4.89	9.0	4.56			25.0	7.79+
49.5	4.98	48.0	4.98	25.0	5.08				
66.5	5.16			50.0	5.52				
91.5	5.01								
115.5	5.14								

* Data of Series A set back 4.5 hours to allow for lag.

† See footnote of Table 4.

‡ In the case of E corrections could not be applied as bottles for Series D were depleted and data for the demand due to residual food could not be obtained. Consequently the results for E are undoubtedly too high.

An unavoidable error, involved in this method of studying the effects of increased bacterial populations on resultant oxidations, is noted in the total amounts of oxygen used in series B, C, D and E. The rate of oxygen utilization apparently increases very rapidly with any increase in the number and activity of the bacterial cells present. Thus the rate was much more rapid in B than it was in A, more rapid in C than in B, etc. For instance, in filling the bottles of series D the first bottle filled from the carboy was examined to determine its dissolved oxygen content. It contained 8.08 parts per million of dissolved oxy-

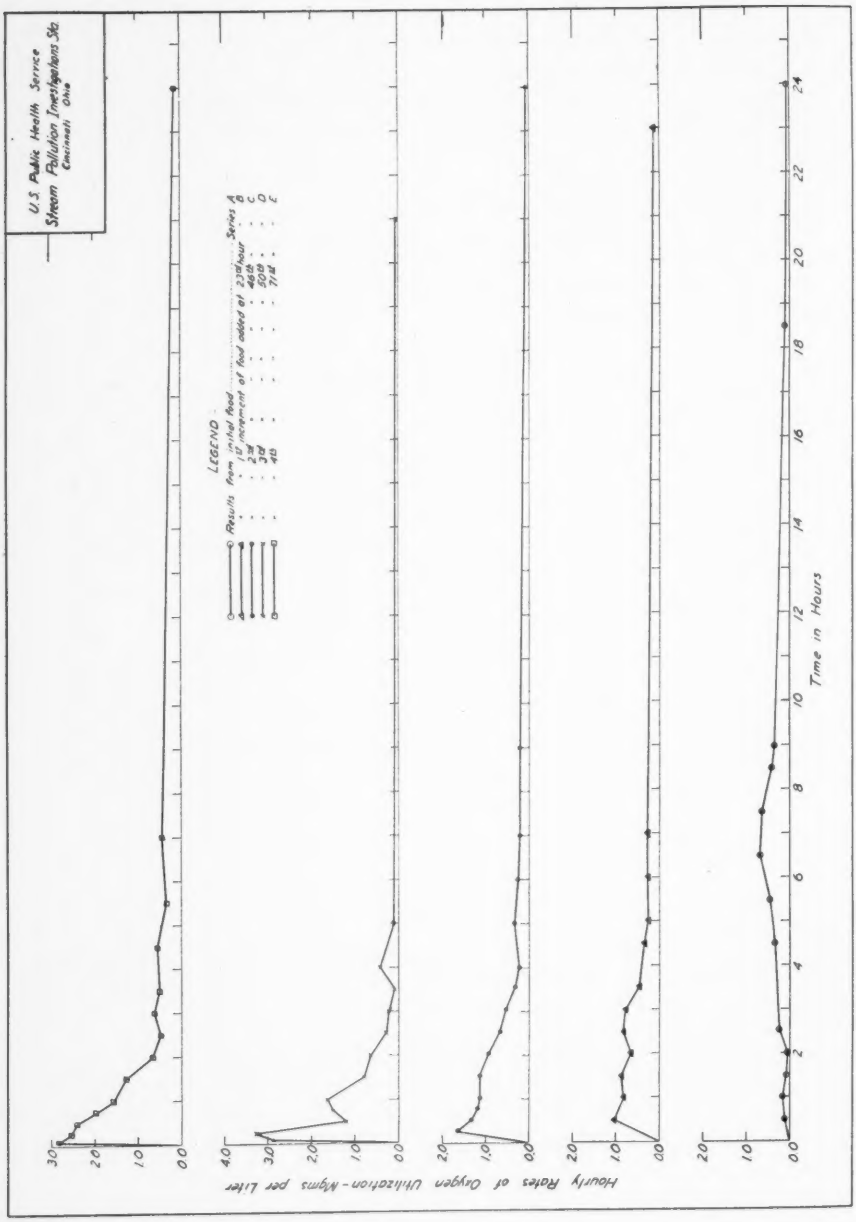
U.S. Public Health Service
Stream Pollution Investigations Sta.
Cincinnati, Ohio
LEGEND
Results from initial feed ..... Series A
" 1st increment of feed added at 23rd hour . . B
" 2nd " " " " 46th " . . C
" 3rd " " " " 90th " . . D
" 4th " " " " 114th " . . E
Hourly Rates of Oxygen Utilization - Mgms per Liter
Time in Hours

FIG. 5.—Hourly rates of oxygen utilization by *Bact. aerogenes* at 20° C., when refed at various intervals. Results have been corrected in each case for residual O_2 requirements of preceding food increments.

gen. The last bottle filled from this carboy (five minutes were required to fill all of the bottles) when titrated showed a dissolved oxygen content of 7.80 p.p.m. Thus there is a very definite indication that at least 0.28 p.p.m. (8.08 — 7.80 = 0.28) of oxygen were used during this 5 minute interval. Similarly in series E the first bottle filled contained 7.79 p.p.m., while the last one showed 7.46 p.p.m., an indicated loss of 0.33 p.p.m. In this instance 7 minutes were required to fill all the bottles.

When the concentrated medium was added to each carboy, just prior to putting up each series as in B, C, D and E, at least 5 minutes were

TABLE VI.—*Hourly Rate of Oxygen Utilization by Bact. Aerogenes Growing in Dilute Medium when Refed at Various Intervals. Results, Calculated from Corrected Data Presented in Table V, are Expressed in Mgs. O_2 per Liter per Hour. These Data are Plotted in Fig. 5*

Series A *		Series B Refed at 23d hr.		Series C Refed at 46th hr.		Series D Refed at 50th hr.		Series E ‡ Refed at 71st hr.	
Time in Hours	Mgs. O_2	Time † in Hours	Mgs. O_2	Time † in Hours	Mgs. O_2	Time † in Hours	Mgs. O_2	Time † in Hours	Mgs. O_2
0.5	0.12	0.5	1.02	0.25	1.64	0.08+	2.88	0.12	2.83
1.0	0.16	1.0	0.82	0.50	1.32	0.25	3.20	0.25	2.52
1.5	0.06	1.5	0.88	0.75	1.20	0.50	1.20	0.5	2.40
2.0	0.04	2.0	0.64	1.0	1.12	0.75	1.48	0.75	1.96
2.5	0.24	2.5	0.84	1.5	1.14	1.0	1.64	1.0	1.56
4.5	0.34	3.0	0.80	2.0	0.94	1.5	0.78	1.5	1.28
5.5	0.44	3.5	0.48	2.5	0.68	2.0	0.62	2.0	0.66
6.5	0.69	4.5	0.35	3.0	0.54	2.5	0.26	2.5	0.48
7.5	0.65	5.0	0.26	3.5	0.32	3.0	0.20	3.0	0.64
8.5	0.41	6.0	0.28	4.0	0.24	3.5	0.08	3.5	0.50
9.0	0.36	7.0	0.28	5.0	0.35	4.0	0.40	4.5	0.57
18.5	0.10	23.0	0.06	6.0	0.29	5.0	0.09	5.5	0.34
25.5	0.05	26.0	0.00	7.0	0.22	21.0	0.05	7.0	0.46
		31.0	0.02	9.0	0.22			25.0	0.11
				25.0	0.03				

* Data of Series A set back 4.5 hours to allow for initial lag.

† Hours from time of each addition of food.

‡ Data of Series E are not corrected for residual B.O.D.

employed each time in getting this thoroughly mixed with the contents of each carboy prior to distribution in B.O.D. bottles. Thus, with the evidence presented in mind, it is reasonable to presume that considerable oxygen, probably at least 0.3 p.p.m., was used for the oxidation of the added food during this 5-minute interval of mixing. While this does indicate a failure to measure the total oxygen requirement it does not invalidate observations on the rate of oxidation and rather serves to emphasize the rapid rate of oxygen utilization under these conditions.

The bacteriological counts obtained from this experiment are presented in Table VII and in Fig. 6. These results have not been re-

duced to a comparable basis dependent on a single food increment, for reasons which will be discussed. The procedure employed for obtaining the bacteriological data (plating on agar with three duplicate plates at each dilution) was not sufficiently accurate to yield satisfactory results for such a comparison. That is, it is known that the production of 1,000,000 bacterial cells may induce an oxygen requirement of about

TABLE VII.—*Numbers of Bact. Aerogenes Developing in Dilute Medium When Periodically Enriched with Fresh Food*

Bacteria in Millions

Series A			Series B		Series C		Series D		Series E	
Hours From Start	Hours	Bacteria per ml.	* Hrs.	Bacteria per ml.	* Hrs.	Bacteria per ml.	* Hrs.	Bacteria per ml.	* Hrs.	Bacteria per ml.
0.0	As set	.505	0.0	19.400	0.0	20.200	0.0	24.700	0.0	40.000
0.5	back for	.530	0.5	16.400	0.25	22.000	0.08	—	0.12	—
1.0	lag cf.	.590	1.0	23.200	0.5	18.600	0.25	21.000	0.25	41.700
1.5	Table 4	.565	1.5	21.000	0.75	22.000	0.5	22.700	0.5	27.400
2.0	and 5	.500	2.0	21.600	1.0	19.500	0.75	28.700	0.75	35.400
2.5		.550	2.5	22.800	1.5	23.400	1.0	26.000	1.0	39.700
3.0		.615	3.0	23.100	2.0	30.100	1.5	29.700	1.5	32.700
3.5		.640	3.5	23.000	2.5	27.500	2.0	27.300	2.0	41.700
4.5	0.0	.610	4.5	24.000	3.0	24.900	2.5	29.000	2.5	43.400
5.0	0.5	.540	5.0	24.600	3.5	—	3.0	48.700	3.0	37.300
5.5	1.0	.480	6.0	24.200	4.0	27.900	3.5	37.000	3.5	—
6.0	1.5	.865	7.0	27.200	5.0	28.000	4.0	48.000	4.5	58.000
6.5	2.0	.845	23.0	33.500	6.0	30.600	5.0	—	5.5	51.000
7.0	2.5	1.100	26.0	29.400	7.0	35.300	21.0	48.300	7.0	—
9.0	4.5	2.580	31.0	37.000	9.0	—			25.0	43.300
10.0	5.5	2.980	48.0	30.000	25.0	36.000				
11.0	6.5	4.180			50.0	58.400				
12.0	7.5	6.640								
13.0	8.5	8.780								
13.5	9.0	—								
23.0	18.5	21.000								
30.0	25.5	23.200								
46.0	41.5	22.600								
54.0	49.5	26.300								
71.0	66.5	24.900								
96.0	91.5	29.100								
120.0	115.5	—								

* Hours from time of each addition of food.

1.0 mg. It is also known that the probable error of the bacterial counting method employed is, on the average, at least 10 per cent for a single determination. Consequently when the number of bacteria present is in the range of 10,000,000 or more per ml., which was the case in series B, C, D and E, an increase in the number of bacteria sufficient to create an oxygen requirement of at least 1.0 mg. per liter might be concealed

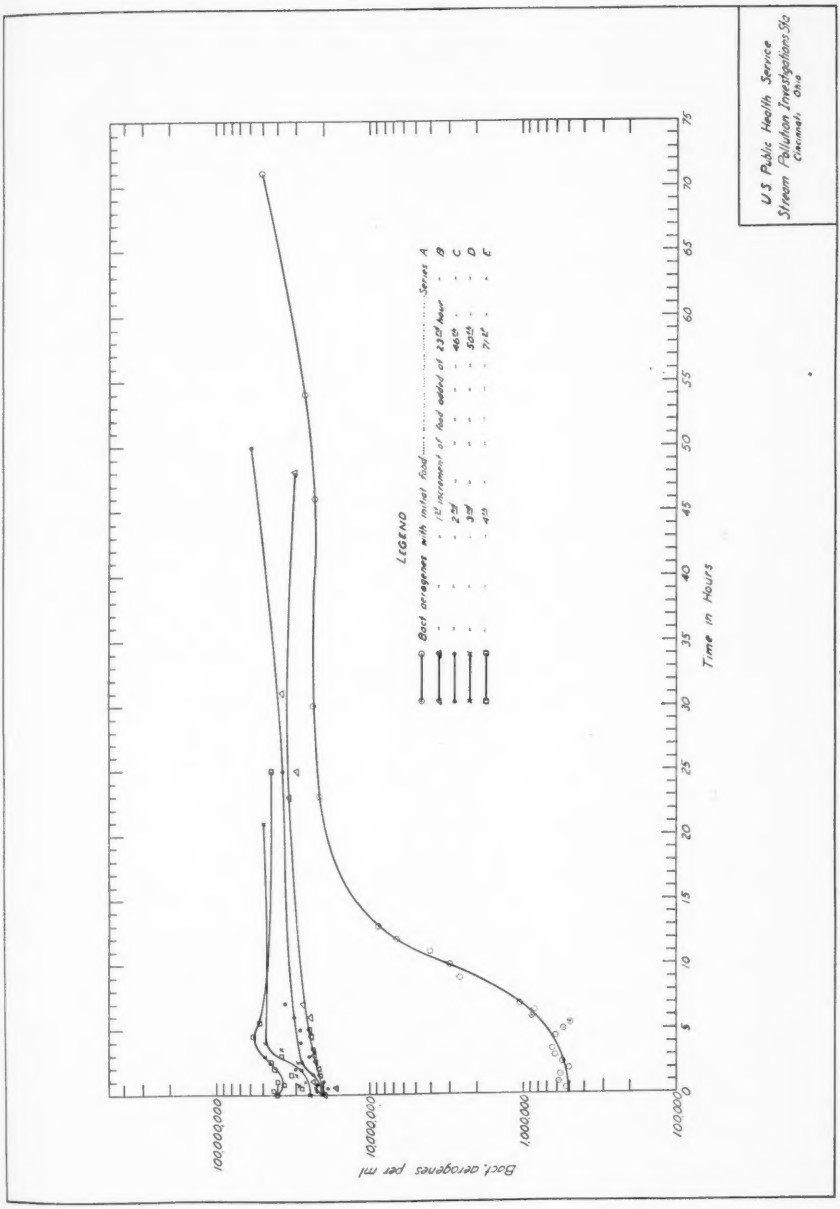

Fig. 6.—Numbers of *Bact. aerogenes* developing at 20° C., when refed with identical portions of the same medium at various intervals. Results are plotted with time of addition of food as zero hour in each case.

entirely by the probable error of the bacterial determination. This situation renders it difficult to make any definite comparisons between the numbers of bacteria present and the amount of oxidation produced. (Greater accuracy could be achieved by making 25 or more plates at each dilution but the limited personnel available for this work does not permit such extensive plating and counting with the frequency of sampling required for this study.)

However, in spite of the errors involved in this second series of experiments in the determination of both the total oxygen requirement and the bacterial counts, the results obtained indicate certain trends. These trends are significant and considered in connection with the results of the first series of experiments, which they definitely confirm, they are of much greater significance.

II. Effect of Dispersion of Bacterial Flocs on the Course of Oxidation

In studies which have been reported (4) (5) it has been suggested that activated sludge developed by pure cultures of zoogleal bacteria simulates natural activated sludge to a remarkable degree, both in the production of a firm and tenacious floc and in the purification and oxidation accomplished by the sludge. In bringing about the oxidation reported, this pure culture sludge was kept continuously dispersed throughout the medium by aeration. This sludge in a quiescent state settles quite rapidly. Consideration is now given to tests to indicate the part that this dispersion of the flocs may play in the efficiency of the oxidation process.

Preparation.—A pure culture activated sludge (Zoogleal Culture, Z4, in standard synthetic sewage) was developed by the fill and draw method as described (5) for use in this test. When sludge had developed to the extent of 325 p.p.m., in terms of dry suspended matter, it was used. Sterile B.O.D. bottles, siphons, etc., were prepared as in the preceding experiments.

Procedure.—Standard biochemical oxygen demand determinations were made by the usual excess oxygen dilution method. As the observations were to be made over a 5-hour period only, dilute synthetic medium of 10-fold strength was employed. Twelve hundred ml. of the pure culture activated sludge was centrifuged and the precipitate washed through three changes of dilution water by centrifuging down each time. The final precipitate was made up to 150 ml. with sterile dilution water and 64 ml. of this mixture were added to 6,400 ml. of dilute synthetic medium (10-fold). After thorough mixing the contents were transferred carefully by sterile siphon to B.O.D. bottles. Gentle mixing was continued throughout the transfer period to insure a uniform distribution of the sludge. Two bottles were examined at once to determine their dissolved oxygen content. One-half of the remaining bottles were allowed to stand quiescent while the other half were inverted and twirled at one-minute intervals until the time of test. While this amount of agitation probably did not equal the mixing

obtained by the aeration method, it did keep the floc from settling out and maintained a fair degree of dispersion.

The floc in the quiescent bottles was, of course, thoroughly dispersed at the start of the examination but after 30 minutes practically all of the floc in these bottles was in a thin layer in the bottom. However, not all of the bacteria present were held in this settled floc. As always happens when floc is treated in this manner a large number of the bacteria become detached from the flocs and dispersed throughout the medium as individual cells or as very fine bits of floc.

Examinations for their dissolved oxygen contents were made on two bottles from each set (quiescent and agitated) at the 0.5, 1.5, 3.0 and 5.0 hour periods of storage. As the contents of the bottles were identical in each set any difference in the amount of dissolved oxygen utilized could be attributed to the effect of agitation produced in one set.

Results.—The differences between the amount of dissolved oxygen present at the start and the amounts present at the end of each examination interval, *i.e.,* the average amount of oxygen used in each set for each time interval, are recorded in Table VIII. These results are

TABLE VIII.—*Oxygen Utilization by Pure Culture Activated Sludge When Sludge is Kept Dispersed Throughout and When it is Allowed to Settle to Bottom of the Container.*

Condition of Sludge	Oxygen used in Mgs. per liter after following hours			
	0.5	1.5	3.0	5.0
Dispersed	0.73	2.09	5.19	7.74*
Settled	0.51	1.14	2.35	3.80

* This determination was made at the 4.25 hour as results indicated that these bottles might be entirely depleted of oxygen by the 5th hour.

also presented in Fig. 7. The oxygen requirement in the bottles with the sludge dispersed was approximately twice that observed in the quiescent bottles, indicating the marked effect of dispersion of the sludge on the rate of oxidation. With the sludge settled out, any contact between available food and the bacteria in the settled floc would be dependent on the rate of diffusion of the food particles and of oxygen to the bottom layers, whereas with a dispersed floc greater opportunity for bacterial cell, oxygen and food particle contact would be provided. It is noted that the difference between the oxygen requirements for the two sets at the first 0.5 hour period is not nearly so great as for subsequent periods. This is probably due to the fact that the sludge was equally well dispersed initially in both series. If the bacteria in the sludge flocs had not been slightly dispersed by the treatment given, the difference between the quiescent and agitated bottles would probably have been greater.

This experiment, as well as the preceding ones, has been repeated a number of times so that the trends indicated may be considered as fairly definitely established.

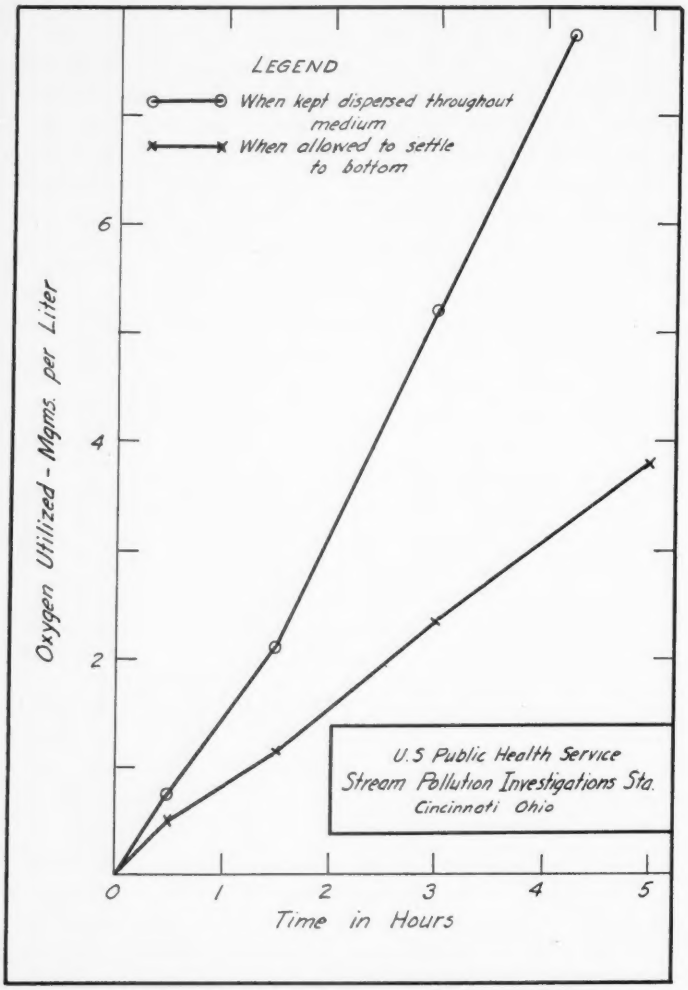

FIG. 7.—Oxygen utilization by activated sludge when sludge is kept distributed throughout the medium and when it is allowed to settle to the bottom of container.

Discussion of Results.—It is interesting to note the application of the results from all three series of experiments to oxidation processes. When the initial bacterial population is limited to 500,000, or less, per ml. (as is practically always the case in oxygen requirement determinations made by the excess oxygen dilution method), the incidence of measurable oxidation is slow, varying with the number of organisms present, and oxidation proceeds in an orderly fashion with the maximum hourly rate attained only after several hours of incubation. This is in keeping with the orderly progress of bacterial growth, under such conditions, until bacterial numbers are reached which require increased amounts of oxygen for their metabolic activity.

When the initial bacterial population is greater (3,000,000 to 10,000,000, or more, per ml.), the incidence of measurable oxidation is very rapid; the maximum hourly rate of oxidation is attained very early in the life of the sample (from at once to 4 hours) and thereafter the hourly rate of oxidation decreases quite rapidly. This diminution in rate of oxidation, after the hourly peak rate has been reached, would be presumed to be caused by the decrease in the amount of oxidizable food available per bacterial unit (*i.e.*, a situation is reached soon when this amount of food is no longer sufficient to stimulate growth and reproduction but is sufficient only to maintain life). The results presented at this time and those reported earlier (1) indicate that the amount of oxygen required for bacterial life processes under such limited nutritional conditions is very small indeed (less than 0.01 mg. oxygen per million bacteria per day).

With all initial bacterial concentrations tried, regardless of the time required for the incidence of measurable oxidation, and regardless of the time of occurrence of the maximum hourly rate of oxidation, the total oxygen requirement after a 24-hour or longer period was approximately the same in all cases with the same concentrations of food and the same bacterial species acting. It appears logical to assume that, if these final bacterial populations had been reduced below their limiting number, renewed growth with its consequent increase in oxidation would have ensued as was proven in the previous report (1). In fact, in biological processes such bacterial reductions or removals have been shown to be essential for the completion of both natural and artificial methods of purification.

While the bacterial maxima observed in the second series of experiments, using an aerogenes culture which tended to form flocs, were considerably greater than those obtained in the preceding experiment using a non-clumping strain of aerogenes, the increased bacterial numbers secured in this manner did not approach the huge concentrations of bacteria present in activated sludge. In pure culture activated sludge with a suspended solids content of about 1,000 p.p.m. (dry weight) the bacterial content is at least 10,000,000,000 * per ml. It is suggested, therefore, that this phenomenon of the initial acceleration of oxidation induced by increased initial numbers of bacteria is the explanation of the very greatly increased rates of oxidations reported for activated sludge (5, 6).

Namely, that here when the initial numbers of bacteria were increased from a few thousands up to 10 millions per ml., the portion of the total oxygen requirement satisfied during the first few hours was very greatly increased, it would be reasonable to conclude that in an

* This figure is based on an average of a number of determinations. The drastic methods required to disperse the cells contained in flocs, to make counting possible, probably kills or at least injures many of the included cells. Moreover, the flocs are undoubtedly not completely dispersed and the cultural methods employed may not have been suitable for the growth and demonstration of all of the effective organisms present, particularly so in the case of normal activated sludge. Consequently the figure given, 10 billion bacteria per ml., is considered a conservative estimate of the probable number of bacteria present in such concentrations of sludge.

activated sludge, with the concentration of bacteria present at the start of aeration raised to 10 billions or more per ml., a still larger proportion of the total oxygen requirement would be satisfied during the first few hours.

From a bacteriological viewpoint such deductions appear logical, for in the activated sludge method of sewage purification, the continuance of the process, namely sustained growth and oxidation, is dependent on: (1) a continuous input of sufficient, available bacterial food (by an inflow of suitable sewage of appropriate strength), (2) a continuous reduction of the excess bacterial population (by the removal of accumulated sludge in excess of required volumes) and (3) the withdrawal of by-products detrimental to bacterial growth (by the discharge of effluent).

Conclusions

The rate of oxidation of bacterial food during the early hours of incubation is dependent on the number of living units of bacteria present at the start; the greater the initial numbers the more extensive the initial oxidation.

The rate of oxidation is also influenced by the degree of dispersion of bacteria, or bacterial flocs, in the presence of a dispersed food; adequate dispersion is required to produce extensive oxidation.

A logical explanation, based on this influence of bacterial numbers and their dispersion on oxidation, is provided for the mechanism of the very rapid rate of oxidation obtained with pure culture activated sludges and of the same phenomenon as it occurs in the activated sludge process of sewage treatment.

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Plant Operation

SOME OF THE LEGAL ASPECTS OF FINANCING SEWERAGE PROJECTS IN PENNSYLVANIA MUNICIPALITIES *

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Within the last three years, new methods of financing sewerage projects have been enacted into law in Pennsylvania. Not so long ago a Pennsylvania municipality had only two available methods; now there are at least four. Considering that only two methods were available for almost fifty years, we can appreciate the progress that has been made when the number doubles in less than five years.

It has been a source of some surprise to me to discover the number of communities that do not have adequate sewerage facilities. I do not intend to elaborate on what is or is not adequate, but I think I may be permitted to assume that where the State has threatened a borough, or a township, or a city with legal proceedings unless a sewer system is constructed, with a disposal plant, pumping station, and all the "trimmings," that borough or township or city does not have adequate sewerage facilities.

The reason that new methods of financing sewerage projects by municipalities have only recently been added to the laws of Pennsylvania is because the demand for new methods is a matter of recent development. While there were only two methods by which a sewerage project could be financed, a municipality chose either one or the other, or, as happened in many instances, decided both methods were unsatisfactory and did nothing. There was no substantial outcry of the citizens if the project was dropped; a few perhaps complained, but the rest were either complacent or discouraged.

Now, however, the State government is stepping in with more forceful demands, backed by acts which enable it to compel communities to "do something about it." As another factor, with the grants of funds from the Federal Government, the municipalities now have less reason for saying they cannot afford to provide adequate sewerage facilities for their residents. Both of these factors are, of course, recent developments, and since they are the contributing factors to legislation adding to the methods of financing sewerage projects, it is only natural that such legislation should be even more recent.

It will not be possible to go into the details of all the methods of financing sewerage projects in Pennsylvania, but it may be of interest

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to outline the four major methods and to comment briefly upon their various advantages and disadvantages.

I. General Obligation Bond

The first and obvious method is the issuance by the municipality of general obligation bonds, the proceeds of which are to pay all the costs of constructing a complete sewerage system, including the disposal plant, pumping station, and trunk lines. The ability of a municipality, otherwise permitted by law, to issue bonds for this purpose is dependent upon its borrowing capacity. Under the Constitution (Section 8 of Article IX) and the enabling Act of April 16, 1874, P.L. 65, a municipality may incur a debt up to two per cent of its assessed valuation of property for taxable purposes without obtaining the consent of the electors, and up to seven per cent with the consent of the electors. If a municipality has already incurred a debt for other municipal purposes, the first question is whether it still has sufficient borrowing capacity to issue bonds in the necessary amount.

Several additional factors should be considered in connection with this method. These bonds are retired by taxes levied on all the property owners in the municipality (Section 10 of Article IX of the Constitution). If all the properties are not to be benefited by the sewers, the result is that taxpayers and property owners on A street, where there is to be no sewer, are helping to pay for the sewers on Z street. There is no legal objection to this but there well might be vocal, not to say political objections. Even though the municipality should assess the property owners on Z street for the assessable costs, still the property owners on A street will, through taxes, be paying for the non-assessable costs of the sewers and also will pay the assessable costs of the sewers of abutting property owners who do not pay their assessments.

This type of financing should be restricted to a municipality that is almost completely built up, such as a city or a borough. Not only is it a questionable policy to compel the property owners on A street, where there is to be no sewer, to help pay for the sewers on Z street, but it is even more questionable to compel owners of a considerably large portion of property which is not built up, and will not be for many years, if ever, and thus has no need for sewers, to help pay the cost of sewers in the built-up portions. It would seem that the law had taken this into consideration. While the codes of cities, boroughs, and first class townships permit the issuance of general obligations for sewer projects, the second class township code does not give this power, but restricts second class townships to financing the cost by assessments, without even the power to issue assessment bonds.

Finally, it may often be a fact, which should be considered, that the cost of a complete sewerage system will exhaust a large proportion of the borrowing capacity of a municipality. There might well be some question whether a municipality is justified in using all of its borrowing

capacity for one type of improvement, no matter how beneficial it may be.

II. Assessment Against Abutting Property

The second method of financing sewerage projects is by assessing the cost against the property owners abutting the sewers. This method is seldom, if ever, used exclusively, since a part of the cost of every sewer system is non-assessable, and it is usually necessary to supplement the assessments with the proceeds of general obligation bonds.

There are two ways of assessing the costs of part of a sewer system against the abutting properties: one is by benefits and the other by the so-called foot front rule. The latter has become the more popular and is undoubtedly the less cumbersome. The former requires that a special jury, called the jury of view, shall determine the benefits for which the property owners shall be assessed. The foot front rule is much simpler, in that the municipality divides the assessable cost by the assessable front footage and charges according to the frontage. Even this method, however, is not the easiest to work out, particularly when it comes to the exemptions where there are sewers on two or three sides of one property. The statutes and the courts seem to recognize, however, that adjustments must always be made, and permit and sustain equitable adjustments where it seems necessary.

This particular method of financing sewerage projects has existed for over fifty years and up to date has been the most popular, for obvious reasons. Where a municipality cannot afford to issue general obligation bonds for an entire sewerage project, it often can issue enough to provide funds for the non-assessable costs, such as the disposal plant and trunk lines, allowing the cost of the collection system proper to be paid by the properties abutting on and benefited by the sewers.

Formerly, I believe, it was customary to pay the contractors by assigning them the assessments for collection. This could never have been a very satisfactory arrangement from the standpoint of the contractors, since the collections were probably slow and in the meantime the contractors were compelled to meet the pay rolls out of their own pockets. In the days when contractors had plenty of cash—if there ever were such days—this system may have been feasible. Nowadays it is not even possible. In any event, the practice now is for the municipality to levy and collect the assessments, but in the meantime to pay the contractor with assessment bonds, which he must market at once in order to pay his bills. These assessment bonds are secured solely by the assessments and represent an obligation by the municipality only to levy the assessments and pay them over, when collected, to the holders of the bonds. It is a definite obligation by the municipalities to perform certain duties, but the bonds do not pledge the credit of the municipality nor do they rest on the taxing power, as do general obligation bonds.

The bond itself recites that it is secured solely upon assessments levied, or to be levied, and collected. If, however, the municipality fails to perform its obligations to levy and pay over the assessments, it renders itself subject to a suit and to a judgment, which is collectible out of the taxes.

The light-hearted fashion in which municipalities in the past have financed sewer systems by the issuance of assessment bonds and then failed either to levy the assessments or to comply with the specific provisions of the law as to their collection, or to segregate the collections when received, has resulted in much litigation in the State, almost invariably to the disadvantage of the municipality. After several years of receiving no interest and several more years of receiving no principal upon the maturities of the bonds, the holders have brought suits against the municipalities, alleging negligence or breach of contract arising from improper levy of assessments or in the collection of the assessments, or for some other reason. In most of these cases judgments have been entered against the municipality, sometimes because the municipality was itself anxious to have the bonds reduced to judgments so that general obligations might be issued to fund them; and sometimes, notwithstanding defenses raised by the municipality, the judge or the jury have held the municipality liable. I mention this situation for the particular reason that, in discussing methods of financing sewer projects with a municipality, the difficulties inherent in the issuance of these assessment bonds should be pointed out. As with many things, once we have received the benefits of a transaction, it is sometimes hard to remember that we still have certain duties on our part to perform. Furthermore, it certainly does not help the credit of a municipality to have judgments aggregating a large sum entered against it.

I might mention briefly that there were passed at three consecutive sessions of the Legislature, 1929, 1931 and 1933, identical acts which purport to transmute assessment bonds outstanding as of the dates of the acts into general obligation bonds, provided the limitations of the Constitution with respect to debt limits are not in any particular case exceeded. I could discourse at some length on these acts which have have been upheld by several decisions of lower courts in Pennsylvania and by the Federal District Court in Philadelphia, but I will refrain from doing so for several reasons, the most substantial of which is that I am now engaged in litigation involving these acts.

Assessment bonds are still a popular method of financing part of the costs of sewerage projects, and it remains to be seen whether or not the new methods recently authorized will supplant it.

I might mention at this point that there is another method of financing sewer projects which depends upon assessments. This method is to issue initially a certain amount of general obligation bonds, for instance, $100,000, to defray the cost of a sewer system. After the work has been completed, assessments are levied, collected, and placed in a special fund. From this fund, the municipality proceeds to finance

further sewer construction which in turn is assessed and the assessments placed in the special fund. This is sometimes referred to as the Revolving Fund method, and would seem to me to be effective in a limited number of instances. Its success is dependent upon the ability of the municipality to collect promptly a large portion of the assessments so that the sewer construction work may progress steadily. Otherwise the cost might be out of all proportion in that new contracts might have to be entered into for each separate piece of work.

III. Financing by Separate Municipal Authority

In 1935 the Legislature of Pennsylvania passed an act known as the "Municipality Authorities Act of 1935." While an authority is new in this State, it has been known in other states for some years. The act defines an "authority" as "a body politic and corporate created pursuant to this act," and both courts and dictionaries have expounded at some length as to just what that means. For all practical purposes it is substantially the same as a corporation, and the Act therefore authorizes the formation by a municipality of a corporation which is separate and distinct from the municipality itself. One of the purposes for which a municipal authority may be organized is for "constructing, improving, maintaining and operating . . . sewers, sewer systems, sewage treatment works." Among the powers granted to the municipal authority is "to borrow money, make and issue . . . bonds of the authority" and for that purpose to enter into a deed of trust or indenture in which the revenues received by the authority are pledged as security for the bonds. An amendment in 1937 to the Act of 1935 specifically prohibits any receiver from selling or mortgaging the assets of the authority. The revenue of the authority is produced by charges for the use of the facilities of, or for the services rendered by, the authority or projects thereof.

Thus, if a municipality is unable or unwilling to finance a sewerage project either by general obligation bonds or by assessment bonds, it may organize a municipal authority, or a separate corporation, which has the power to construct a sewerage system, treatment plant, and pumping stations, to charge the property owners for the use of the sewers, and to finance the construction by the issuance of bonds secured by the sewer rentals.

It must seem curious to a layman that a municipality that is unable to build a sewer system, need only assume a different costume, so to speak, and proceed without much difficulty. There are, of course, legal reasons for this situation. A municipality, being a creature of the State, is exceedingly limited in what it may do. It is even more limited by the constitution and statutes as to the debt it may incur, both as to amount and purpose. As I have said, it may not incur a debt exceeding two per cent of its assessed valuation of taxable property without the consent of the electors, and may not, even with such consent, exceed seven per cent. Over thirty years ago there was an act which author-

ized a Borough to purchase a water works and to provide funds to pay for such water works by issuing bonds which would be secured solely by the water works and its revenues. In 1912 Warren Borough, which had an inadequate borrowing capacity, proposed to purchase a water works and to issue bonds in an amount exceeding its borrowing capacity, but secured solely by the water works and its revenues. Lesser, a taxpayer, sought to enjoin the issuance of the bonds and the Supreme Court held that the bonds, notwithstanding the restriction of security to the property and revenues of the water works, were general obligations of the Borough, and thus could not be issued. This opinion, which appears in Volume 237 of the Pennsylvania Supreme Court Reports at page 501, goes into a very extensive discussion of this aspect of municipal indebtedness and is particularly significant in any consideration of the legal status of a municipal authority. In any event, it required an amendment to the Constitution (Section 15 of Article IX) to enable a municipality to issue bonds secured solely by water works property and revenues, without having such bonds constitute an indebtedness subject to the limitations of Section 8 of Article IX of the Constitution.

One of the points stressed in this Supreme Court opinion was the fact that even though the Borough did not obligate itself to pay the bonds, nevertheless Borough property, that is the water works, could be taken by the bondholders in the event of default. When the Supreme Court first had before it the status of an authority (Tranter *vs.* Allegheny County Authority, 316 Pa. 65 (1934)) this very question was considered and the fact that no property of the municipality would be taken in case of the default of payment of the bonds was used to distinguish that situation from the one involved in the case of Lesser *vs.* Warren Borough. Under the Municipality Authority Act of 1935, a municipality is authorized to "lease, lend, grant or convey to the authority" sewers, sewer systems, and sewage treatment works upon such terms and conditions as are mutually satisfactory, and it is thus possible that the authority may be holding or operating facilities that were formerly owned by the municipality. The amendment of 1937, however, specifically provides that the property of the authority may not be taken in the event of a default, so that this further insulates the difficulties arising in the Warren Borough case from the status of the authority.

No Supreme Court opinion, to my knowledge, has been delivered on the constitutionality of the Municipality Authority Act. The State Authority Act was before the Court twice—the first time the Court held the State Authority Act invalid and the second time, upon the basis of additional facts, valid. The language of the Court in these two cases (Kelley *vs.* Earle, 320 Pa. 449, and Kelley *vs.* Earle, 325 Pa. 337) as well as that in the Tranter case, would seem to indicate that if it can be shown that the project of a municipal authority was self-liquidating —that is, that the revenues would be sufficient to pay the operating

expenses and the principal and interest on the bonds, this method of financing sewerage projects could legally be followed.

Practically speaking, the proceedings which a municipal authority would take in constructing and financing a sewerage project would be the same as those followed by a private corporation or a public utility corporation. Once the municipal officials had put on the costume of a municipal authority they would pass resolutions and approve indentures and other documents in exactly the same way that any Board of Directors of a company would do. For that reason, and particularly because the only security of the bonds issued by the authority would be the revenues from the sewer system, a large responsibility falls upon the engineer for the authority. He must not only estimate with great care the cost of construction, but he must be particularly careful of his estimate of revenues to be received by the authority. A municipal bond is sold upon the basis of the faith, credit, and taxing power of the municipality. An authority bond is sold upon the basis of the estimated revenues. If the prospective purchasers have confidence in the engineers' estimate they will bid at low interest rates for the bonds. If they have little or no confidence, the interest rates will be high, if there are any bidders at all. I may say that I have continually emphasized to municipal authorities the importance of choosing engineers of recognized standing and ability.

It is needless to say that this device of an authority has proved and will prove of great benefit to municipalities in this State. If a municipality does not even have the borrowing power to issue general obligations in an amount sufficient to pay the non-assessable costs of a much needed sewer system, there should be some way by which the sewer system could be constructed. It is still too soon to say whether this method will prove the most satisfactory, but certainly it is a step in the right direction.

IV. Financing by Non-Debt Revenue Bonds

The most recent method of financing sewerage projects is by the issuance of "Non-Debt Revenue Sewer Bonds." The power to issue these bonds was given townships of the second class by the Act of May 7, 1937, P.L. 571; townships of the first class by the Act of May 7, 1937, P.L. 574; cities of the third class by the Act of May 7, 1937, P.L. 578; and to boroughs by the Act of May 7, 1937, P.L. 582. All of these acts are substantially identical, and, in my opinion, if they are upheld by the Supreme Court, represent the most satisfactory method of financing sewerage projects. In many respects this method is similar to that of creating an authority. Both provide for indentures or deeds of trust and the bonds do not pledge the credit of the municipality, nor become a lien upon the properties, but are secured solely by the revenues from the sewer system. In the case of authorities, the power to collect revenues, as we have seen, is given in the Authority Act itself; under this method the revenues are derived from annual sewer rentals,

or charges, which the various municipalities are authorized to impose by the Act of May 14, 1937, P.L. 630, which amends the Act of July 18, 1935, P.L. 1280. The annual sewer rentals or charges which may be imposed may be sufficient to meet any or all of the following classes of expense:

(*a*) The amount expended annually by the municipality in the operation, maintenance, repair, alteration, inspection, depreciation, or other expenses in relation to such sewer, sewer system, or sewage treatment works;

(*b*) Such annual amount as may be necessary to provide for the amortization of the non-debt revenue bonds issued by the municipality in the construction or acquisition of such sewer, sewage system, or sewage treatment works, and interest thereon, in order that said improvements may become self-liquidating, and

(*c*) Sufficient to establish a margin of safety of ten per centum.

In the case of an authority, the right is given to make charges "at reasonable rates, to be determined by it, for the purpose of providing for the payment of the expenses of the Authority, the construction, improvement, repair, maintenance and operation of its facilities and properties, the payment of the principal of and interest on its obligations, and to fulfill the terms and provisions of any agreements made with the purchasers or holders of any such obligations."

There may perhaps be little to choose from so far as the items which go to make up the charges or rates are concerned. There is, however, this great difference. The annual rental or charge imposed by the municipality is made a lien on the properties served, and as such the liens may be filed in the office of the prothonotary and collected in the manner provided by law for the filing and collection of municipal claims. In other words, these annual rentals or charges are thus placed in the same category as assessments and other municipal claims. The authority, however, is in no better position than a public utility. It must collect its delinquent revenues by suits at law, obtain judgments and only then do they become liens, and even then the lien has not the priority position of a municipal claim. The authority might threaten to turn off the sewage service as a threat to obtain payment, but the carrying out of this threat may be restricted by the Board of Health.

I believe that in the last analysis this one factor—that the annual sewer rental or charge becomes a lien on the property—will prove to make Non-Debt Revenue Sewer Bonds the most popular method of financing sewerage projects. It has the advantage of imposing a charge only upon those being served by the sewer and not upon taxpayers who may derive no direct benefits from sewers, and thus would seem more desirable than general obligation bonds. It permits the imposition of annual charges not only to pay principal and interest on bonds but to operate and maintain the sewer system, and thus has an advantage over assessment bonds, since the assessments cover only the cost of construction and do not, of course, include operating costs. And

finally, as we have seen, the charges are a lien against the properties and are more easily and promptly collectible than the charges which would be made by the authority.

There is one question still to be decided so far as these Non-Debt Revenue Sewer Bonds are concerned and that is the rather important one of whether they may be issued without imposing a debt upon the municipality, or, in other words, whether that portion of the act which provides that the bonds shall not create any debt, nor be a charge against the general revenues, is constitutional. One municipality is already planning to have a test case brought to determine this question, and, since we represent that municipality, I will not attempt to argue the case at this time. There would seem to be authority to sustain these acts and we hope to be able to persuade the Court to that effect.

In the case of these bonds, as with the authority bonds, there is need for careful engineering estimates of cost of construction and of the net revenues. Here again, the purchasers of the bonds cannot look to the credit or taxing power of the municipality, but must rely on estimates of revenue. Without a competent engineer to act for the municipality, there would be little use in going to all the bother of issuing this type of bond, since there would be no bidders for them. It has been my practice to emphasize this factor very strongly whenever we are consulted about the issuance of these bonds. The engineering involved in a sewer project requires professional handling, and only those who are competent should be asked to advise a municipality.

Discussion

Mr. W. L. Stevenson, *Consulting Engineer, Formerly Chief Engineer, Pa. Dept. of Health:* Mr. Appel has shown at least four ways whereby the municipalities in the State of Pennsylvania are enabled to finance the construction and operation of sewerage systems. But those powers remain merely words in the statute books until human beings do things to make them available and produce the money. So, between these powers and the actual production of the money, stand human beings with their personal ideas and their wishes and desires, and they must be persuaded one way or the other in order to put those things into effect. For example, the council of a municipality, or the commissioners of a township, are empowered, as Mr. Appel told you, to incur a debt up to 2 per cent, but those commissioners or councilmen are human beings and they are responsive to the wishes of their constituents and they must be convinced that it is to the benefit of the municipality and conforms to the wishes of the majority of their constituents before they will exercise this power. If the debt to be incurred exceeds 2 per cent, and approaches 7 per cent, then the commissioners or the councilmen must be persuaded to submit to the electorate the matter of a bond issue. That means there is a larger group of human beings that must be convinced or persuaded in order that the majority of them will vote for the bond issue, else it fails. And many

of us know only too well how these bond issues do fail. These same principles apply in the matter of a municipal authority and the application of the sewer rental acts. Those in authority must be convinced that it is a good thing to do. As a rule the people and the officials are more inclined to favor the expenditure of public funds for public works from which the citizens themselves obtain a direct benefit, such as playgrounds, schools, improved fire protection, and the like.

Speaking of sewerage, the people can see the comfort and the convenience of a sewer system, and funds for that purpose are obtained more easily than funds for a sewage treatment works, which is chiefly for the benefit of users of water farther down the stream, or for the public at large. That is one among many good reasons why the Commonwealth needs, and now has, legislation intended to compel municipalities to provide funds in order to protect the general public interest of those people living along the stream below the municipality in question. How can those who are interested in extended sewage facilities bring about this needful state of mind on the part of the officials and citizens? We try to convince them, and I think one of the weaknesses in public health work is that in trying to convince them we make a general statement that sewer systems and sewage treatment work is for the protection of public health. There have been many data collected to prove this by cold figures in the matter of pure and improved water supplies, but I am sorry to say, so far as I have knowledge, that similar information has not been obtained to show reductions in the death rate upon the installation of sewer systems and sewage treatment plants. I suppose those data are available.

Just one more thought, and that is the matter of sewer rental. If the public water supply is delivered to a premise, the householder or the property owner has been quite used to paying his water rent. If you don't have a telephone, you don't have a telephone bill, and if milk isn't delivered, you don't pay a milk bill. Sewer rental, placing a financial burden on properties that receive the benefits of a sewer system, has seemed to me a just and equitable way of financing. The fact remains that people feel it is a new tax, after they have already paid the assessment bill, paid their share of the construction of the sewer, probably a tappage fee for making the connection, and also the plumber's bill.

It is very fortunate that Mr. W. W. Morehouse, of the City of Dayton, Ohio, has come to this meeting. Mr. Morehouse has told me how the officials of Dayton showed the citizens of Dayton that the sewer rental is fair. I hope that he will speak on that subject so that he may give you the practical application of some of the things I have said to you.

MR. W. W. MOREHOUSE: I am not here to attempt to discuss Mr. Appel's paper, but I came to outline some of our experiences in putting through sewer rentals.

We operate under a city manager form of government, and the directors of the various departments are appointed by the city manager,

with the approval of the commission. Originally sewerage was under the service director, which is customary under that form of government in Ohio, but the city officials expanded the division of water. As I told Mr. Stevenson, some of our friends call it the "Department of Water—New and Used." We call it the, "Department of Water—New and Used—with by-products of reclaimed waters and fertilizers."

The City of Dayton was the first large city in Ohio to take advantage of sewer rentals for the financing of the operation and maintenance of its sewerage facilities. Before the construction of the sewage plant, both storm water and sanitary sewage were discharged into the Miami River at the lower part of the city and nature was supposed to take its course. Relatively small amounts for operating funds were taken from the general tax funds of the city and sewers were constructed from bond funds.

The first contract for the sewage treatment plant was let in October 1927 and the inability to get additional tax funds for the new activities led us to take advantage of the Ohio Sewer Rental Law. The ordinance was passed in December 1927 and took effect the first of the following year. The Division of Water was expanded into a Department of Water which covered all the activities of the Sewer and Water Divisions except the design of new sewers, which was left under the city engineer as before.

The machinery for billing and collection was already set up, and only required expansion to do the additional work. Billing machines were installed and the sewer rental was added as a second item on the water bill. The first bills sent out were accompanied by a printed notice explaining the additional charge.

The rate set up was intended to produce revenue to operate the sewage treatment plant, pumping stations, the sewer maintenance division, and to retire a portion of the bonds issued for construction.

The rate fixed the minimum charge at $1.00 per quarter, the minimum quantity being 3,000 cubic feet. This was fixed to eliminate about 90 per cent of the requests for rebate for water used for sprinkling lawns. The sewage quantities to which the rate was applied are based primarily on the water measured by the meters of the water works, but it is obviously unfair to charge for water used for processing, air conditioning, etc., which could be discharged to the storm sewers or elsewhere, and adjustments were made under these conditions. Also, it was just as unfair not to charge for sanitary sewage which originated from a private water supply. Each unusual case was made the subject of a survey in which the water going to the sanitary sewers was determined. If the amount was unsatisfactory to the customer, he was requested to buy meters to measure the amount.

By authority of the state legislation and the city ordinance, the amounts charged for sewer rental become a lien on the property and if not paid, is certified to the county auditor and placed on the tax duplicate and collected as are other taxes. The amounts certified have been surprisingly small and will eventually be paid.

Our collections have produced sufficient revenue for the operation of all parts of the sewerage system, have paid the interest and bond retirements on a $500,000 issue of the original construction bonds, and the water works have been paid for one-third of billing and collection expenses and about the same portion of the expense of the director's office. We have also financed a large portion of the city's share of a W.P.A. program for the extension of the plant to provide complete treatment of the sewage.

Revenue amounts to slightly more than $1.00 per capita and is about one-third of the total amount taken in by the Water Department.

The bills are a standard bill of the stub accounting variety, such as used in many of the utilities at the present time. It is printed on post card stock and is in three parts. One part is the original bill sent out through the mail as a post card; the second is the delinquent notice, also a post card; and the third part is the office copy or accounting stub. Bills are printed and addressed on a 3,700 Addressograph and the billing is done on a National Utility Billing Machine.

PRESIDENT FRIEL: Mr. Emerson, have you any comments?

MR. C. A. EMERSON, JR. (George B. Gascoigne & Associates, New York City): Mr. Chairman, just a very few words.

With Attorney Appel's very comprehensive review of the legal points, and Engineer Stevenson's non-discussive discussion which covered a great many other points, and Commissioner Morehouse's statement as to the practical application in Dayton, the subject seems to have been covered in a very well-balanced way. There are one or two points which I am sure could be emphasized.

Both of the first two speakers have stressed the necessity of careful planning and the study of revenue which must be produced by the new system. Revenue bonds have been in existence and sewer rentals, in one form or another, have been in existence in many parts of the country for many years. In some portions of New England sewer rentals have been in vogue close to fifty years. In various parts of the Middle West they have been very much more popular than in Pennsylvania. But irrespective of this, revenue bonds are not ordinarily as popular with brokers and banking interests as the general obligation bonds, because they do not have the general faith and credit of the municipality back of them. Therefore, they ordinarily carry somewhat higher rates of interest. The fact that the project may be legally sound and economically wise does not necessarily mean that it is popular with the public. We are just old-fashioned enough in general, I think, to realize that this added bill is an increase in taxes.

In changing to a sewer rental proposition, there must be the education of the public so they can see and appreciate and be convinced of the advantages of it. The engineering study has to cover the whole project, and in a way which is convincing to the bankers who are to purchase the bonds, so that they can see that in a certain time the necessary revenue will be produced, for sinking fund, amortization

charges and operating expenses, with a reasonable balance for emergencies.

The method of assessing in proportion to the water bill has these complications: not all the water reaches the sewer system, and conversely many industries and some homes have private wells and are discharging more into the sewer system than they receive through the water meter. One of the advantages of the method of procedure is that when your rate schedule is set up, ordinarily the increase in population of the municipality will take care of the increase in annual expenses of operation, so that your rate schedule is not exposed to the mad scramble of the budget made up by the local council each year, as is your estimate of the operating expenses if you have to go to council each year. It is not so likely to be disturbed by council, because it is more difficult to do that than it is to cut down your request for certain appropriations for this, that, and the other. So I believe there are compensating features, and it certainly is a step in the right direction, because it is a direct payment for something which has been received. Remember that the municipality has to be educated, and if that educational program is not backed by adequate data, it is bound to fail.

Mr. C. L. Siebert (Pennsylvania Department of Health, Harrisburg, Pa.): I would like to know whether it would be legal in Pennsylvania to collect a sewer rental before the work is actually done and in operation? Can you charge for something which you have not delivered?

I would also like to know how much leeway municipalities in Pennsylvania have, that is, whether sewer rentals can be based upon the water consumption, the number of fixtures on a property, the population within the residence, or the invested value of seated lands or improved property.

A few days ago, being interested in sewage treatment facilities in my own town, I communicated with Mr. E. W. Ray about the issuance of non-debt revenue bonds. They are not saleable at the present time. I believe there is some possibility of the Federal Government purchasing non-debt revenue bonds up to 55 per cent of the cost, in addition to its 45 per cent P.W.A. grant. In other words, there is some possibility of selling the bonds to the federal authorities before their constitutionality has been declared. However, that has not been definitely decided. But it is an interesting hope.

Mr. George F. Baer Appel: As to your first question, I am not sure that I can give you a definite answer at this time. The Act declares that you are to charge annual rentals on properties served, or to be served, by the sewerage. I am not at all sure that would justify your charging a sewer rental before the system is put into operation. It looks as though it were unfair, and quite likely the courts would not sustain any such charge. But there is that provision in the Act that reads, "properties served or to be served." I don't know what it means except that you can pass an ordinance, charging sewer rentals

on properties when they are served. To that extent it may well be prospective.

In answer to your second question, there is nothing in the Act which limits specifically the amounts of sewer rental, except that the Act does provide for what purposes you can assess sewer rentals. They are defined pretty carefully, but at the same time, as I said in the paper, they cover such things as operating expenses, maintenance, repair, alterations, inspection, depreciation, and other expenses, and it would be hard for someone to come in and show that the charge was too high. And at the same time you have the added margin of safety in the 10 per cent, so I think it would be difficult to show that it was unreasonable if there was any justification at all for the annual charge.

MR. C. H. YOUNG (Penna. Dept. of Health, Meadville, Pa.): I think revenue bonds are going to be more and more a matter of interest in Pennsylvania towns. You spoke of a case which is to be tested as to its constitutionality, and I would like to ask how long it will be before that is done. Will it be done within the time limit so that our towns will be able to use that method of financing, and be able to get the P.W.A. loans?

MR. APPEL: All I can tell you is that we hope to have that case before the lower courts the early part of this summer. In that event an immediate appeal will no doubt be taken, but it can not be argued before the Supreme Court until the latter part of September. Even if you urged the court to hand down a quick decision they wouldn't do it for several weeks thereafter. I am not sure, but regarding the P.W.A., since you must have all the commitments in sometime in August, it is going to be difficult for the municipalities to designate what kind of plans they want to follow, but they might designate certain alternate methods of financing. I haven't consulted any one about the P.W.A. and I don't know.

MR. YOUNG: Can boroughs issue assessment bonds?

MR. APPEL: Yes, indeed. Many of them have.

MR. L. H. ENSLOW (*Editor Water Works and Sewerage,* New York City): In Pennsylvania this method of collecting sewer rentals is more of a problem than in Ohio and other states, because here you have so many privately owned water companies. A nice question is: "In cases where the water utility is privately owned, what would be Mr. Appel's suggestion as to the most feasible method of collecting sewer rentals?"

MR. MOREHOUSE: It isn't necessary to base it on the water meter amounts. You can have your rates fixed by the old fixture rate method and you can use that, charging so much for each connection. The only reason we use the meter readings is because it gives as fair a breakdown of the different amounts that the people use as we know. People that use a lot of water pay for it, and they pay more for the sewer rental.

MR. ENSLOW: That isn't the answer to my question.

PRESIDENT FRIEL: Maybe no one wants to answer it. I will ask Mr. Stevenson what he suggests, where a water supply is privately owned, regarding the matter of collecting sewer rental?

MR. STEVENSON: I stated before that I wasn't here to discuss Mr. Appel's paper, and for the same reason I am not going to discuss this. However, I think perhaps I can answer it in part.

When the original Sewer Bill of 1935 was drafted, Mr. John Fertig was Director of the Legislative Reference Bureau, and the matter was discussed with him. He said, "Legally, the essence of the matter is that the charge shall be equitable, and if the charge is not equitable, the courts will not sustain it."

There have been many ways of fixing these charges. For example, a question just as complicated as your question is: "What charge shall be made for the admission of industrial wastes?"

I haven't answered your question, but the thought is that the charge shall be equitable.

MR. H. M. FREEBURN (Penna. Department of Health, Philadelphia, Pa.): In almost all of the communities in the Philadelphia district where sewer rental is in effect, water is served by private water companies. The method in use there is to base the charge on a fixture rate base. Almost all of them have adopted that method. There have been no objections and it has been quite successful.

MR. APPEL: This case which is being brought up before the court does provide that the sewer rental shall be based upon the fixtures, and I believe there is a private water supply in the community where the question is being raised.

MR. C. E. HARTMAN (St. Marys, Pa.): It doesn't appear to me that the fixture rate is equitable.

PRESIDENT FRIEL: I have had a little experience in conjunction with sewer rentals, and it has been my experience that the practical way to do it is on the basis of the fixture count. Our township, where Mr. Appel also lives, was the first to establish a sewer rental system. That was in 1905. I believe they were pioneers in the matter of sewer rentals, and the rentals are based upon fixture counts.

This is such a lively question, I think we should continue the discussion.

MR. REEVES NEWSOM (A. W. W. A., New York City): Something was said about attempting to improve their public relations, and that they might find some difficulty in doing so. I doubt very much if there would be difficulty in making arrangements with the private water company to furnish to its respective communities its take-off of water meter readings. I believe the water company would be glad to cooperate. And I don't believe it would be an insurmountable problem.

MR. MOREHOUSE: If any of you are interested in our sewage legislation and some of the model ordinances in the State of Ohio, if you will write to the Ohio Department of Health, Columbus, Ohio, they would be glad to send a bulletin to you which contains not only the

law but the model ordinances and three different methods of making charges.

Mr. W. C. Emigh (City Engineer, Coatesville, Pa.): In Coatesville, we are using very much the same system of making charges as described by Mr. Morehouse, except we did not make any exceptions for sprinkling and the like, because it would get us into an endless number of objections. Perhaps 20 per cent of the city is on the meter rate and the balance on a flat rate. In either case, we charge 60 per cent of the water bill for sewage disposal.

I quite agree with the gentleman who said that the fixtures are not a fair method of measurement, but it is just as fair for sewage as it is for water.

We need to keep in mind, in any consideration of rate making for sewage, that there is a certain value to the community as a whole. It is perhaps intangible, but certainly there is some value to the community as a whole accruing from the fact that it has a sewer system and sewage treatment works. If it were not so, surely the Chambers of Commerce and such bodies would not make so much of a point of sewage treatment facilities as well as of water. We have for many decades used an assessment system for the construction of the sewers. We feel that to charge the treatment of sewage against the front footage of a vacant lot is not so fair as it is for the construction of a sewer. Also, the trunk sewer comes into the cost of the treatment, rather than in the assessment.

Mr. J. T. Campbell (The Chester Engineers, Pittsburgh, Pa.): I think one point that city officials will be interested in is this: approximately what interest rate will be charged on non-debt revenue bonds? I know that in our experience in Kentucky and Virginia, where we have put in a number of sewer systems which were financed by revenue bonds, the bonds have been purchased by P.W.A. at 4 per cent interest. I was wondering whether Mr. Appel could give us some idea as to the interest rate on such bonds in Pennsylvania.

Mr. Appel: Where general obligation bonds vary in interest rates from 1¼ to 1½, and where special assessment bonds carry 5½ per cent, tax-free, you can make your own decision as to what your non-debt revenue bonds would carry. It is not a municipal bond; it is a little better than the assessment bonds, and would be judged by the banker pretty much on the same basis as a corporation bond, with the additional factor that the rentals may become a lien.

Member: If there is some individual in the community who says that he is not going to pay until he knows whether or not it is legal, how are you going to enforce collection?

Mr. Appel: No charges would be made until it is legal. In other words, the municipality is going to have a test case, and as soon as that has been done and the decision has been handed down by the Supreme Court there will be no question as to its legality.

MEMBER: I have reference to water works. Can you turn off the water if a man refuses to pay? Do you have the legal right to turn off the water if he doesn't pay his sewer rental?

MR. APPEL: I don't know the answer to that, but I don't think they would permit you to turn off the sewer fixtures. I don't think there is any law that would permit that. But you can file a lien, which is an encumbrance on the house, and it is a pretty substantial threat when you want to sell the house.

MR. H. N. HERR (Civil Engineer, Hershey, Pa.): I want to make one statement. I have always considered the matter of basing the sewage rentals on the amount of water, as measured by meter, to be fairly equitable. It is only a matter of comparison. Not all of the water that is used by the consumer goes into the sewer. Our water company is privately owned, and so is the sewage company, but in fixing our sewer rates, it seemed to me that it was the fairest way of getting at a charge.

PRESIDENT FRIEL: Are there any questions? Do you have further comments? I see Mr. Olewiler back there.

MR. G. M. OLEWILER (Supt. Sanitation and Drainage, Ardmore, Pa.): When you speak of assessing by fixtures, I think it is necessary to try to please the people. For instance, the poor man, with but one bath-room in his home, comes in and he is fairly well satisfied, and then when the man who has three or four bath-rooms in his home comes in, in answer to his complaint you must say to him, "You certainly must value yourself higher than the other fellow because you are satisfied to purchase a house with four bath-rooms, and surely you would be willing to pay the increased share of the burden." In our community there was but one man of late years who questioned the assessment, and he went away feeling all right about it after we talked to him.

PRESIDENT FRIEL: This has been a very enlightening session, and I think it has been one of the most interesting sessions we have ever held in our State College meetings.

Industrial Wastes

TREATMENT OF SULFUR DYE WASTE BY THE ACTIVATED SLUDGE PROCESS *

II. Further Studies of Optimum Operating Conditions

By Henry J. Miles and Ralph Porges

Special and Assistant Investigators for the Textile Foundation, Washington, D. C.

Previous investigations by the authors (6) have shown that sulfur dye waste can be successfully treated in conjunction with domestic sewage by the activated sludge process. Since many cities in the textile areas are either treating or planning to treat the mill wastes at municipal sewage plants, it was decided that further studies of optimum operating conditions for these plants would be of value. Although this work was confined to the treatment of black sulfur dye waste, it is believed that the results obtained are applicable to all activated sludge plants handling textile wastes, since a survey of textile waste treatment made in 1936 by Geyer and Perry (1) for the Textile Foundation indicated that black sulfur dye is one of the most difficult of all textile wastes to handle.

Three fundamental factors which affect the purification obtained in an activated sludge plant are the amount of air supplied, the length of aeration period, and the amount of suspended solids carried in the aeration tanks. In a previous paper (6) the authors described a series of experiments made simultaneously in four identical aeration tanks, in which the amount of air supplied and the length of aeration periods were the same, but in which the suspended solids concentrations were kept within different ranges. These experiments were continued with different aeration periods and varying amounts of air; some of the results obtained are presented in this paper. Considerable additional data on the effect of preaeration and studies made throughout the aeration periods are available and will be the basis for the next paper of this series.

Description of Plant

The experimental plant in which these experiments were conducted is located on the property of the Proximity Print Works of Greensboro, North Carolina. (For a detailed description of the plant the reader is referred to the first paper of this series (6).) It consists of a covered platform and an adjoining laboratory. On the platform are mounted the various units of the plant as shown in the general layout (Fig. 1). All tanks are made of heavy sheet iron and include the following units:

A 240 gal. circular mixing tank.
A 210 gal. primary settling tank.
A 720 gal. rectangular aeration tank.

* This research project was carried out under the joint sponsorship of the University of North Carolina and the Textile Foundation.

Seven small aeration tanks each of 40 gal. capacity and approximately 10 in. wide, 23 in. long, and 40 in. high. Each of these small tanks is equipped with a swinging siphon outlet pipe on one side to permit withdrawal of supernatant liquid from any depth.

Sewage was pumped to the plant from a nearby main outfall sewer of the northern section of the City of Greensboro by a one-inch centrifugal pump mounted in a manhole. The sewage was of a weak domestic type but occasional variations of the B.O.D. indicated that some industrial wastes may have been present.

Sulfur dye waste from the mill was dipped with buckets from the dyeing jigs just before they were to be emptied and before any rinse water was added. The wastes were carried by a pipe line to a 240 gal. storage tank at the plant. The storage tank was equipped with a floating cover.

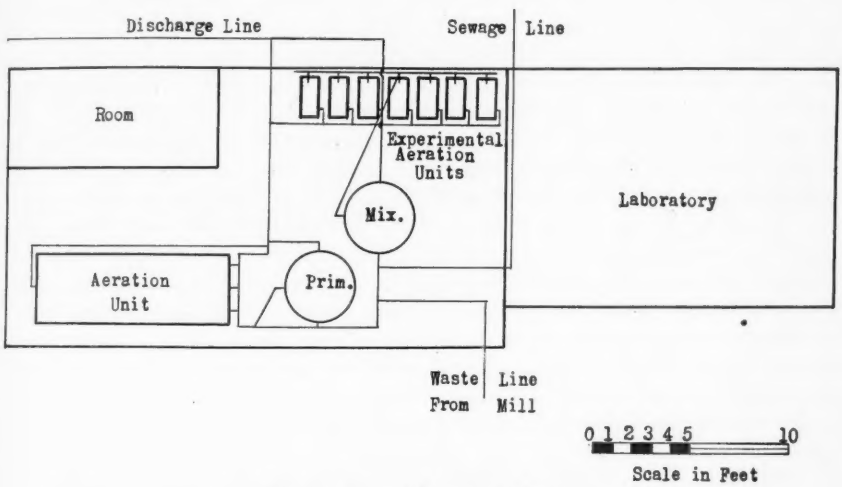

FIG. 1.—General layout of plant.

The dyebath consists of the pigment or dyestuff, sodium sulfide, caustic soda, and water. The sodium sulfide causes the normally insoluble dyestuff to dissolve in the bath. When the bath becomes spent, a neutral salt such as sodium chloride is added to salt out more of the dye. The B.O.D. of the waste averaged about 10,000 p.p.m., the suspended solids 1,000 p.p.m., and the pH 11.5. The waste has an intense black color which even in high dilutions prevents the use of most colorimetric tests.

PROCEDURE

The absence of an activated sludge plant in the vicinity necessitated the accumulation, on a fill-and-draw-basis, of activated sludge in the large aeration tank. Sewage was pumped directly into the tank, presedimentation being omitted because of the low suspended solids con-

tent of the sewage. Aeration was continued for nine hours, using the minimum amount of air conducive to good agitation. The air was then turned off and the solids allowed to settle in the tank for two hours, after which the supernatant liquid was withdrawn through the swinging siphon outlet pipe. This procedure was continued without interruption until sufficient floc had formed.

Portions of the floc were added to each of the small aeration tanks in such quantities that when diluted to 36 gal. with raw unsettled sewage from the mixing tank, the suspended solids concentrations were approximately 500, 1,500, 2,500, and 3,500 p.p.m. respectively. The small tanks were operated on the fill-and-draw basis on the same schedule as described for the large aeration tank, with the exception that one per cent dye was added to the raw sewage in the mixing tank and thoroughly mixed for 15 min. before being added to the aeration tanks, thereby insuring doses of uniform consistency. At the end of the settling periods, 24 gal. of supernatant liquid were drawn off from each tank and replaced with equal volumes of sewage-dye mixture, thereby insuring a constant volume of 36 gal. in each of the aeration tanks throughout all the runs. Air was supplied at the rate of 15 cu. ft. per hour, or 3.75 cu. ft. per gal. of mixture in the tank, per run.

When observations and analyses showed that the floc had become acclimated to the dye, routine tests were made on every run throughout the duration of the experiment. Acclimatization runs were used not only to accustom the floc to the dyewaste but also to saturate the activated floc with dye before beginning routine tests, inasmuch as previous studies had shown that new floc produced by the aeration of sewage alone removed large quantities of dye when first brought into contact with it. This high rate of color removal usually persisted for only a few runs (referred to in this paper as "acclimatization runs") after which the daily rate of color removal became constant for any given tank.

The same procedure was repeated with varying amounts of air and different aeration periods. The length of the experiments varied from five to fourteen consecutive "test runs" after the initial "acclimatization runs." Results of these "test runs" are believed by the authors to be as representative as longer activated sludge experiments of a similar nature conducted by them in the same experimental plant and extending over a period of three months (6). The acclimatization runs usually extended over a few days.

Each experiment was started with fresh activated sludge from the large aeration tank, which was kept in operation on the original nine-hour schedule. The same concentration of dye, one per cent by volume of the raw sewage, was used throughout all the experiments, as previous experiments had shown that that amount would give representative results.

The suspended solids concentrations in the tanks were checked just before the end of each run with the centrifuge and adjusted when necessary by drawing off some of the tank mixtures while they were still

being aerated. When such adjustments were necessary, less supernatant liquid was drawn off after settling, the volume of return sludge being kept at 12 gal. (33 1/3 per cent) per tank in all runs.

The following tests were made for purposes of control:

Sewage-dye mixture as added to the aeration tanks—B.O.D., suspended solids, and color.

Aeration tank mixture just before the end of the aeration period—B.O.D., suspended solids, centrifuged solids, and settling.

Final effluent, *i.e.,* aeration tank supernatant liquid after one-half hour settling—B.O.D., suspended solids, color, and dissolved oxygen.

All analyses were performed according to "Standard Methods of Water and Sewage Analysis" of the American Public Health Association except where modifications were necessary to allow for the color produced by the dye. All modifications are noted in the following summary of the methods used:

B.O.D.—According to "Standard Methods" using 300 p.p.m. sodium bicarbonate dilution water. Incubation at 20° C. for 5 days.

Centrifuged Solids.—A 50 ml. sample was centrifuged for 5 min. at approximately 1,800 r.p.m. and the volume of sediment correlated with suspended solids determinations made on the same sample. This test was used for a rapid determination of suspended solids for plant control.

Color.—It was necessary to devise some standards of our own as the platinum-cobalt colors would not match the tints produced by the dye. The sulfur waste as discharged from the jigs, before dilution with rinse water, was arbitrarily assumed to have a color intensity of 10,000 and portions of it were diluted with tap water until colors were obtained which could be compared with the samples to be tested. With dilutions greater than 1,000 our color standards are approximately 1/10 that of the platinum-cobalt standards, *i.e.,* a color of 10 on our scale is very roughly equal to 100 on the platinum-cobalt scale. As the dye has an inherent tendency to precipitate on most any surface available, it was necessary to renew the standards each week.

Settling.—Liter samples were allowed to settle in one-liter graduated cylinders for 30 minutes, and the volume of sediment noted as a percentage of the total volume. The cylinders were always placed out of doors and never in the direct sunlight so as to be comparable to the settling conditions in the aeration tanks.

Dissolved Oxygen.—According to "Standard Methods" using the Rideal Stewart modification of the Winkler method. This analysis was made on samples of effluent obtained after one half hour settling in the aeration tanks, immediately after collection.

Results

The combinations of air and aeration periods studied are given in Table I. The minimum rate at which air was supplied was determined

by the least amount which would keep the floc in suspension and the maximum rate by the greatest amount of air which could be supplied without violently agitating the floc and dispersing it.

TABLE I

Series	Number of Consecutive Test Runs	Length of Each Run (Aeration Period) (Hrs.)	Amount of Air Supplied		Settling Time Between Runs (Hrs.)
			Cubic Feet per Gallon	Cubic Feet per Hour	
A	6	4	1.67	15	2
B	10	4	2.56	23	2
C	9	6	2.50	15	2
D	5	6	3.84	23	2
E	6	9	2.50	10	3
F	10	9	3.75	15	3
G	14	9	3.75	15	3
H	14	9	5.75	23	3

The results of the individual analyses made during the various runs are summarized in Table II and Figs. 2, 3, and 4.

TABLE II

	Length of Aeration Period Hrs.	Amount of Air Supplied cu. ft. per. gal.	Average Analyses of Sewage-Dye Mixture as Added to Aeration Tanks			Average Dissolved Oxygen in Effluents from Aeration Tanks			
			B.O.D. P.p.m.	Suspended Solids P.p.m.	Color	Tank 1	Tank 2	Tank 3	Tank 4
A	4	1.67	307	193	80	0.4	1.3	1.0	0.9
B	4	2.56	337	309	82	0.8	2.3	1.7	1.8
C	6	2.50	263	230	81	2.1	2.6	1.5	0.8
D	6	3.84	232	163	80	2.3	4.4	4.7	4.0
E	9	2.50	269	242	72	4.1	2.8	2.6	2.1
F	9	3.75	239	145	88	7.5	8.8	8.3	8.2
G	9	3.75	279	181	81	5.3	4.7	3.6	2.6
H	9	5.75	384	265	81	6.4	6.0	5.1	4.2

Table II shows the average B.O.D., suspended solids, and color of the sewage-dye mixtures as added to the aeration tanks, and the average dissolved oxygen content of the effluents from these tanks.

In Figs. 2, 3, and 4 the average B.O.D., suspended solids, and color removal, respectively, obtained in each tank for each series of runs are plotted against the average suspended solids concentrations maintained in the tanks during that particular series of runs.

Formation of Floc With and Without Dye.—Two of the small aeration tanks were operated in parallel for a period of about two weeks

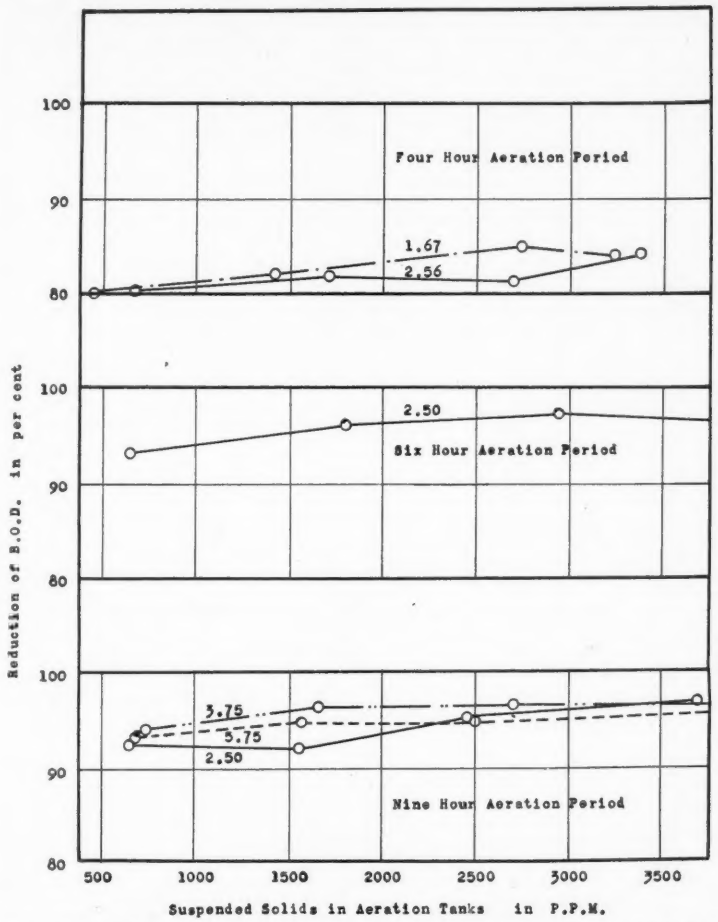

FIG. 2.—Curves showing purification obtained as measured by reduction of B.O.D. in four aeration tanks containing various amounts of suspended solids. Numbers on curves indicate volume of air supplied in cubic feet per gallon of aerating mixture.

on the nine-hour aeration schedule described in this paper. To one tank fresh unsettled sewage was added at the beginning of each run and to the other the same mixture plus one per cent dye by volume. Activated floc was formed in both tanks at about the same rate, the dye having apparently no retarding effect on its formation but, on the contrary, slightly accelerating it. When the floc produced by the aeration of sewage alone was first used to purify a sewage-dye mixture, unusually high color removal was obtained. This high removal lasted for only a few runs during which the floc gradually lost its original brown color and became black. Thereafter, this floc produced the same purification as the floc which had been formed from the sewage-dye mixture and no further differences between the two flocs or their purifying properties could be detected.

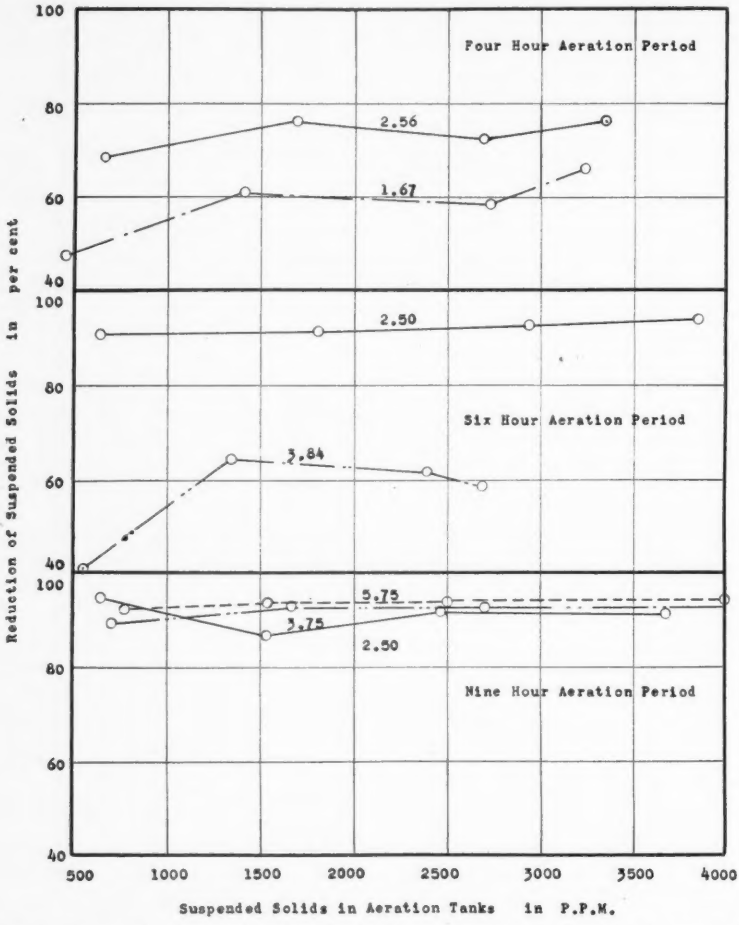

FIG. 3.—Curves showing purification obtained as measured by reduction of suspended solids in four aeration tanks containing various amounts of suspended solids. Numbers on curves indicate volume of air supplied in cubic feet per gallon of aerating mixture.

DISCUSSION

Effect of Length of Aeration Period.—Referring to the three curves in each of Figs. 2, 3, and 4, showing the purification obtained by supplying the same amount of air (2.5 cu. ft. per gal. of tank volume) at different rates, the pronounced effect of the length of aeration period is seen.

Whereas the maximum reduction in B.O.D. obtained in four hours was 84 per cent, the same amount of air distributed over a period of six hours resulted in 97.5 per cent removal of B.O.D. Increasing the aeration period to nine hours resulted in no further removals of B.O.D. and in some cases in slight decreases.

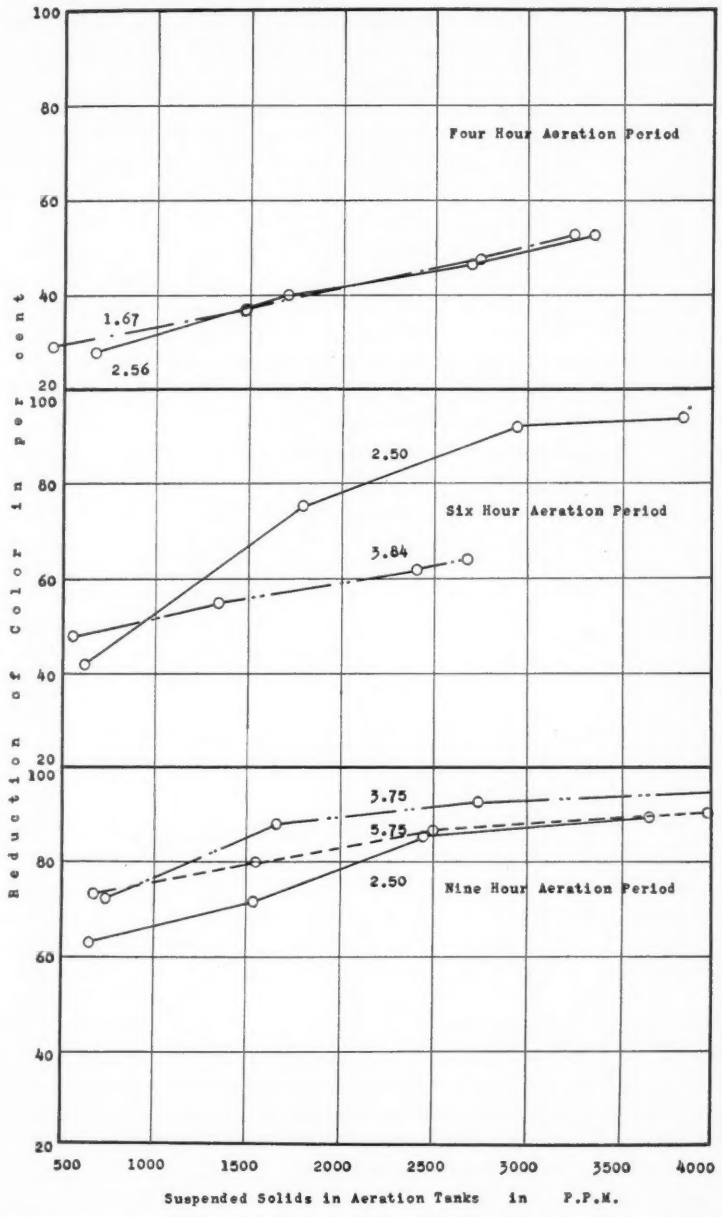

FIG. 4.—Curves showing purification obtained as measured by reduction of color in four aeration tanks containing various amounts of suspended solids. Numbers on curves indicate volume of air supplied in cubic feet per gallon of aerating mixture.

Figure 3 illustrates the increased efficiency in removal of suspended solids of the six-hour run over that of four hours. The maximum removals were 94 and 77 per cent, respectively. No additional purification was gained in the nine hour runs.

Figure 4 illustrates the improvement in removal of color of six-hour treatment over that of four hours. Increasing the aeration time to nine hours resulted in higher color removals for the lower suspended solids concentrations but slightly less for the higher concentrations.

McNamee (5), in studying the oxygen utilization of sewage in the presence of activated sludge found that when "good" sludge was used the oxygen demand of the sewage alone increased rapidly during the first six hours of aeration and dropped off slowly thereafter until the end of aeration (24 hours). With "poor" sludge the oxygen demand of the sewage alone increased during the entire aeration period. This may be interpreted as indicating that six hours aeration was sufficient for that particular sewage when using "good" floc.

Grant, Hurwitz, and Mohlman (2) claim that with shorter periods of aeration, reaeration of the floc becomes increasingly more important to take care of the absorbed but not fully oxidized material in the sludge. It might be assumed that in our four-hour runs this accumulation of organic matter was probably responsible for decreased efficiency of purification; however, analyses of the volatile content of the floc made just before the end of every run, showed no significant trends from the beginning to the end of the series for any one aeration tank.

Between series of measured runs when the aeration period was sometimes as long as 24 hours, it was found that the resulting effluents were high in suspended matter and turbidity, indicating a mechanical breaking up of the floc by over-aeration. Heukelekian (3), when comparing 16 and 8 hour aeration periods in the laboratory obtained a B.O.D. reduction of 72 to 85 per cent in the former case as compared to 80 to 97 per cent in the latter.

When discussing the three sets of curves in Figs. 2, 3, and 4 it must be remembered that when the same amount of air is distributed uniformly over aeration periods of different lengths, the longer the aeration period, the less will be the amount of air supplied per unit of time. It is well known from studies of Kessler and Nichols (4) and others that the oxygen demand of sewage sludge mixtures varies throughout the aeration period and is highest near the beginning. It is possible that during the nine-hour runs the rate at which the air was supplied was not sufficient to meet the initial demands of the sewage-sludge mixtures, thereby resulting in decreased purification in some cases or preventing increased purification in others.

Following the same line of reasoning, the shorter the aeration period, the more violent will be the agitation produced by the 2.5 cu. ft. of air per gallon. The lower purification in the four-hour runs may be attributed in part to an actual breaking-up of the floc by too rapid mixing.

Effect of Variations in Amount of Air Supplied.—It must be remembered that the amounts of air used in these experiments were in excess of that required in actual practice because of the lower hydraulic efficiencies of our small tanks. Although 2.5 cu. ft. of air per gal. caused rapid circulation in the four-hour runs it was barely able to keep the solids in suspension when distributed over nine hours.

As measured by B.O.D. removal, the effect of different quantities of air was very slight, practically within the limits of experimental error. As measured by suspended solids removal, variations in the amount of air had little effect in the nine-hour runs but indicated that optimums existed in the shorter periods.

As measured by color removal, the opposite trend was noted, variations in air having practically no effect in the four-hour runs but considerable effect in the others. These results are in keeping with the observations of other investigators that the amount of air required is that necessary for the maintenance of aerobic conditions throughout the treatment period and also for thorough mixing of the tank contents, and that any air in excess of this amount is of doubtful value, or in some cases harmful. It is interesting to note in this connection that in the six-hour runs the dissolved oxygen in the effluents of the low solids tank (Number one) in both series was practically the same (see "Series C" and "D" in Table II) but as the suspended solids concentrations of the floc increased, the residual dissolved oxygen in the effluents of the series using 3.84 cu. ft. of air per gal. became more and more in excess of that present in the other series. This might indicate that the poor results obtained with 3.84 cu. ft. of air were due to over-aeration. The color of the dye prevented the making of accurate determinations of dissolved oxygen except towards the end of the aeration periods.

Effect of Amount of Floc on Purification.—As measured by B.O.D. removal (Fig. 2), the suspended solids concentration had very little effect on purification, the variation in efficiency of treatment over the entire range of solids concentrations being within 5 per cent for any given set of runs.

Heukelekian (3) studied the effect of suspended solids concentrations ranging from 500 to 3,200 p.p.m. on B.O.D. removal in six laboratory-size aeration tanks, using a procedure similar to ours. With an aeration period of six hours per day followed by no aeration for the remaining 18 hours, he found that the B.O.D. reduction increased with greater suspended solids concentrations, the total variation in any one run being within five per cent.

Ridenour (7), using data compiled from the operating records of a 1.2 m.g.d. plant having a five-hour aeration period and suspended solids concentrations varying from 150 to 3,000 p.p.m., found that with low solids the B.O.D. removal increased rapidly as the solids increased but above a solids concentration of 860 p.p.m. the subsequent increases in purification were within five per cent.

Voelker (8), studying the effect of suspended solids concentrations ranging from 300 to 5,000 p.p.m. in a laboratory size mechanical aeration tank with 6-hour aeration found that purification increased with increased solids but that above 2,000 p.p.m. the gain in B.O.D. removal was very small.

As measured by suspended solids removal, the efficiency increased in the 4 and 6-hour periods with greater amounts of solids until a concentration of 1,500 p.p.m. was reached, after which there was no material improvement. In the nine-hour runs the effect of variations in suspended solids was negligible. Voelker (8), found a similar increase in efficiency with six-hour aeration up to a suspended solids concentration of 1,300 p.p.m. and very little gain thereafter. Ridenour (7) noted the same type of purification curve but found the optimum solids concentration to be about 860 p.p.m.

As measured by color removal, the concentration of suspended solids has a very decided effect (Fig. 4). Color removal increases almost directly proportional to the solids in the aeration tanks until a concentration of between 2,500 and 3,000 p.p.m. is reached, after which the gain in purification is very slight. These results and our observation that at least 50 per cent of the color is removed during the first 1½ hours of aeration indicate that color is removed largely by absorption by the floc. That the dye does not merely accumulate was shown in a previous investigation (6) in which a sewage-dye mixture was added to an aeration tank twice daily for three months, the tank being operated on the fill-and-draw basis. At the end of that period the color removal was as complete as at the beginning despite the fact that no sludge was withdrawn at any time. No color could be separated from the floc by washing with water.

One important consideration in connection with the effect of suspended solids concentration on purification is the ability of aeration tanks containing high concentrations of solids to withstand sudden changes in the composition of raw sewage or sewage-dye mixtures. This tendency has been noted by Grant, Hurwitz, and Mohlman (2) who also contend that when large amounts of sludge are used, the oxygen demand of the sewage is transferred to the sludge and is exerted more uniformly over a longer period of time. This should be a distinct advantage in most plants where air is supplied at a uniform rate.

Summary

The treatment of sulfur dye waste mixed with domestic sewage by the activated sludge process was studied on a semi-plant scale, using the batch process.

Four identical aeration tanks, each of 36 gallons capacity, and containing approximately 500, 1,500, 2,500, and 3,500 p.p.m. of suspended solids were operated simultaneously using equal aeration periods, equal volumes of air, and treating equal volumes of the same sewage-dye mixture. Eight series of runs were made, using aeration periods

varying from 4 to 9 hours in length and air at the rate of 1.67 to 5.75 cu. ft. per gallon of aerating mixture. Each series consisted of several consecutive acclimatization runs to accustom the floc to the conditions of the test followed by 5 to 14 consecutive runs on each of which careful analyses were made. The plant was operated continuously day and night throughout each series.

Variations in the amount of air supplied had little effect on B.O.D. reduction and color removal. The rate of aeration had considerable effect on the reduction of suspended solids in the 4- and 6-hour periods but little effect in the 9-hour periods.

The 6-hour aeration periods were decidedly better than those of 4 hours but very slight additional purification was gained by increasing the period to 9 hours.

The suspended solids concentration carried in the aeration tanks had a decided effect on color removal, the purification being almost directly proportional to the amount of floc present up to a concentration of between 2,500 and 3,000 p.p.m. after which practically no improvement in effluent was gained by increasing the solids.

Variations in the amount of floc had little effect on the reduction of B.O.D. and removal of suspended solids.

Under all conditions of operation the aeration tank containing the most floc was best able to withstand sudden changes in the composition of the sewage-dye mixtures being treated and produced the best appearing effluent.

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DAIRY WASTE ELIMINATION AND SEWAGE DISPOSAL *

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It cannot be repeated too often that the all-important factor in the elimination of dairy waste nuisances is the elimination of waste in the plants themselves. Why spend a great deal of money on treatment of milk solids when they can be recovered within the plant and disposed of in other ways at far lower cost, sometimes with some direct profit? This has been pointed out more and more emphatically every year by practically every writer on the subject (1, 2, 3). We believe we can now say that it is entirely practical and economical to prevent milk losses, collect rinsings, and dispose of spoiled products, excess skim-milk, whey, and buttermilk, in almost all milk plants in such a way that no process of sewage treatment will be required. It may still take a long time for this fact to penetrate through the industry, but when it does, a long step will have been taken toward the elimination of stream pollution. It has been rather difficult to convince some of the milk sanitarians of the large cities that the industry should be permitted to collect drippings and rinsings from equipment instead of letting them go to waste and to pollute the streams. Sanitation officials seem to be afraid that the temptation will be too great to put these drippings and rinsings in with the regular fluid milk supply. There is little danger of this, because the industry, in general, is just as anxious as the health departments to keep the milk supply clean. All the large cities in which we operate now permit the collection of drips and rinsings, but there is still some disagreement as to the proper method for disposal of these products; that is, whether or not they should be used for the manufacture of products used for human consumption or only for animal feed. It is generally admitted that the quality of these drippings and rinsings is fully as good as the quality of the cream generally used for butter manufacture. Consequently, there seems to be no logical reason why we should not be allowed to save the fat from the drippings and rinsings for butter making and then use the skim-milk in the manufacture of by-products.

Every year the industry learns more about how to stop wastes and how to utilize the excess supply of various milk fractions in the manufacture of by-products. The so-called wastes of the dairy industry are really not waste products at all. From a nutritional point of view, they are valuable foodstuffs. The trouble is that our industry is badly unbalanced as regards the supply and demand of the three chief constituents of milk, namely, butterfat, casein, and milk sugar. We feel quite proud of the contribution made by our own research laboratories and unit companies in developing new products and in increasing the

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use of the old ones (3), but the demand for by-products is definitely limited so that from a pollution point of view, recoveries so far are just a drop in the bucket. We are still badly in need of some large outlet for milk-solids-not-fat. Considerable research is being done in this field and some day we shall have the solution of this problem. In the meantime, we shall still have excessive amounts of whey, buttermilk, and skim-milk to dispose of in such a manner that they do not pollute the streams.

Types of Dairy Wastes and Methods of Disposal

The dairy industry has five different kinds of liquid wastes to dispose of and in many cases it will pay to treat all five in different ways.

A. Regular Domestic Waste. The waste from locker rooms, lavatories, and laundries should go to the sanitary sewers in the cities, and to a separate septic tank in the country or in the small towns where no sewerage system is available.

B. Cooling Waters. Sometimes very large amounts of water are used for cooling vacuum pan condensers, ammonia condensers, evaporated milk sterilizers, and pasteurized milk or cream coolers. Where water is cheap, no attempt is made to re-use this water. The vacuum pan condenser water will contain some organic matter from entrainment, but there is not enough of it to cause any trouble. There is consequently no objection to discharging this water to streams, except that some temperature rise must be expected if the stream is small. Water used for cooling evaporated milk sterilizers may be quite badly contaminated if the can closing device is not functioning properly. This represents so much of a loss to the plant that it is likely to be very quickly corrected. In addition to this, the first cooling water is always re-used to preheat the next batch, so that if leaks do occur the load will be distributed over a long time. In city plants, cooling water should go to storm sewers in order to keep the volume in the city disposal plants as low as possible.

C. Spoiled or Excess Products, Such as Whey, Buttermilk and Skimmilk.—(1) Dumping into the Sewer.—This should be permitted only in large cities where there is plenty of dilution. It may be permitted in smaller cities if the dumping is regulated in such a way that the pH in the city's settling tanks never goes below some pre-determined limit, possibly pH 6, since according to Levine (4), a pH below 5.5 severely interferes with the acid-destroying organisms.

(2) Dumping in Streams.—This cannot be strongly enough condemned, except possibly in a few cases where the streams are very large and milk solids may be beneficial as fish food or as food for the organisms which feed the fish. Aerated equalizing tanks may sometimes be helpful, if wastes must be discharged, in order to keep the products fresh and to distribute the load. Aeration will satisfy any immediate oxygen demands.

(3) Dumping in Convenient Places.—In places where there are extensive underground caverns or very porous ground, it is sometimes

possible to drill a hole in the ground and let the waste go down into it. In other places an abandoned stone or gravel quarry can be used for the disposal of almost unlimited amounts of excess products without creating a nuisance. The only cost involved is in the trucking of the products to the dumping place. This cost may sometimes be appreciable. Some friendly farmers will permit dumping on isolated pieces of ground for awhile, but this is not very satisfactory, because of odor and because it makes the soil quite acid.

(4) Lagooning.—This is sometimes done, but is usually unsatisfactory, even if the ground consists of gravel or sand, because it becomes clogged in a very short time. The odor from lagoons will carry quite far and cause complaints.

(5) Return to the Farmer for Animal Feed.—This is strongly recommended whenever no better use can be found. The trouble with this procedure is that the farmer will not always take all that is available, especially if he has to make a special trip to the plant with special cans, most States not permitting the use of the regular milk cans for the return of by-products to the farms. Wider use of tank truck distribution of liquid by-products for animal feed may become common, at least where the roads are good.

(6) Evaporation and Drying.—Equipment for concentrating milk solids is expensive and the prices for the concentrated products hardly pay for the manufacturing costs. Nevertheless, in most places where such equipment is already installed, it is cheaper to continue operation than to dispose of the excess products in other ways.

(7) Manufacture of Special By-products.—Production of casein is usually profitable, but not in the present market. Lactic acid and lactates are profitable, but the demand is definitely limited and equipment is expensive.

(8) Gas Production.—Anaerobic decomposition for fuel gas production has been tried experimentally by Buswell (5), but as far as we know, no commercial installations have been made. Very large digestion tanks would be required (about 30 times the daily whey volume); but with the present great excess of whey solids and the low prices paid, such a process might be economical. A cheese plant could probably develop enough gas to take care of its fuel needs. The digestion would give 80 to 90 per cent B.O.D. reduction (Buswell), but the B.O.D. of the effluent would still be very high. Since the pH would be high and the volume would be relatively small, very little extra treatment might be required. Muers (6) tried anaerobic digestion in a laboratory experiment, but found that the acid increased and the gas production diminished. He was presumably feeding the tanks too fast and did not take the proper precautions to circulate the liquid.

(9) Treatment in Waste Disposal Plants.—This appears rather unattractive because of the size of installation required. We have found, however, that the Guggenheim Process plant at Glen Karn, Ohio, will take an occasional overload of straight whey very well if it is fed gradually to the plant and if plenty of dilution is provided, either with

sewage plant effluent or with fresh water. The present installation will not handle all the whey produced in the cheese plant daily (about 18,000 lb.), but it may take about one-third of it and recover nicely in a day or two. For a daily load, it would probably not be able to handle more than about 2,000 pounds. Even then the B.O.D. of the effluent would be considerably increased, but the sludge would not be spoiled. With a plant of ten times the present capacity, we could probably handle all the whey, but the cost would be high.

Trickling filters appear to be quite sensitive to occasional overloads with whey and recovery is relatively slow; but there is no doubt that trickling filters could be made to handle large amounts of whey at considerably higher rates of flow than now used in conventional installations. However, quite large installations might be required and no by-products would be obtained. If the customary figure of 80 cu. ft. of stone per lb. of B.O.D. per day is assumed, an average size cheese plant, producing 18,000 lb. of whey per day, corresponding to 576 lb. B.O.D., would need a filter 86 feet in diameter, giving an area of 0.13 acre, and 8 ft. depth, and corresponding settling tanks, digesters, and drying beds. The pumping capacity would have to be about 200 g.p.m. or sufficient for recirculating effluent to dilute the whey about 1:60, which would give a flow of about 1 million g.p.d. per acre and a B.O.D. of about 533 p.p.m. in the feed to the filter.

Muers (6) succeeded in handling a 10 per cent whey on filters using only 14 cu. ft. per lb. B.O.D. and this has been confirmed by Barritt (7). We found that even higher loads are possible, but more work is required to prove that the final effluent will be satisfactory at all times. Barritt suggests the use of an activated sludge treatment after the filters and gets very excellent results by this method. We believe we can get just as good results at a lower cost with double or triple treatment on tin can filters.

It might be cheaper to build digesters as suggested by Buswell (5). The same 18,000 lb. of whey per day would require a digester capacity of about 8,600 cubic feet. A trickling filter to handle the effluent from the digesters would need only one-tenth the capacity of the filters mentioned above. In addition gas would be obtained as a by-product of sufficient value to pay for at least part of the investment and operating cost.

D. Drips, Leaks, and First Rinses from Cans, Bottles and Equipment. —As far as drips and leaks are concerned, there is no excuse for these getting down the sewer. By saving the drips from the milk cans alone, we found in one particular case that 2.5 oz. of milk could be saved for each can dumped. By installing a small pre-rinse, another 2.5 oz. could be saved. Eldridge (2) found that about one oz. could be saved per can by a drip saver and another one oz. by a pre-rinse. Roberts (3) reports that one-fourth pt. or 4 oz. could be saved, which closely checks with our figure obtained at a different plant. The amount of possible saving, of course, depends entirely on how fast the plant is dumping its milk. All first rinses from equipment can be saved and used either for

by-products or for animal feed. A certain amount of spillage is unavoidable, but it is quite surprising how low this loss can be if the plant personnel are made to realize its importance and give whole-hearted cooperation. We have been considering the possibility of installing continuous equipment for sampling in proportion to the flow in the sewer lines and then possibly inaugurating some type of premium system for low losses. The losses could easily be determined by total volatile solids minus carbonates or by a simple turbidity test. The oxygen consumed determination might also be a good test, especially for cheese plants. Cheese plants should use the suspended solids test, since all the cheese which goes down the sewer is a direct loss to the plant. Even in plants where vacuum pans and drying rolls are operated, it is now possible to cut down wastes to a negligible amount. Vacuum pans are now carefully rinsed after use and the rinsings collected and a small amount of strong caustic solution is then sprayed on the coils and permitted to soak for a short time. The alkali is rinsed off with a small amount of water and disposed of with other strong rinsings. The coils are scrubbed with a chain cloth and a small amount of rinse water, while a large fine-screen basket is placed under the outlet of the pan to collect as much as possible of the burnt scrapings from the coils. In the operation of drying rolls it is essential to eliminate leaks and splash from the rolls and always to keep dry waste swept up from the floors and from the equipment. When cleaning the rolls, it is important to scrape off and collect as much as possible of milk solids before starting the actual washing operation.

In some cases it may be cheaper to build and operate a treatment plant than to dispose of large volumes of rinsings by trucking to suitable dumping places. In this connetion, two types of waste which belong in between the wastes under headings (*C*) and (*D*) should be particularly mentioned. One is the excessively salty and diluted whey from certain types of cheese, where salt and water are added directly to the batch before the whey is drawn off; the other is the regular cheese wash water which is obtained from washed types of cheese after the whey is drawn off. In most cases it is probably most economical to truck these wastes to some suitable dumping place.

Before any steps are taken to install sewage treatment apparatus, we feel that every plant should be given an opportunity to show what can be done without treatment, but with all proper safeguards to prevent regular or accidental wastes. A convenient pit for flow measurement by bucket or weir should also be available in every plant. Too much guesswork is done and too many mistakes are made, because no facilities are available for sampling and flow measurements. Sampling should be continued every day for at least one full week, because one day's sampling may be very misleading. While it is recognized that no nuisance should be produced in the streams and no disturbance in the city sewage treatment plant, if such a nuisance or disturbance takes place, it is very good to have some place to measure flow and take samples to determine to what extent the plant is really to blame.

E. Actual Washings from Cans, Equipment and Floors.—After all possible savings have been made by the use of drip pans, pre-rinses, and screens, very little milk solids will be contained in the actual alkaline wash water from cans, equipment, and floors.

(1) Dumping to City Sewers or to Streams.—Such procedure should be perfectly satisfactory in 90 per cent of the cases. It will take very little dilution to handle these washings in such a way that no nuisance is produced. As far as streams are concerned, it should always be remembered that only excessive amounts of milk solids are detrimental; a reasonable amount may actually be beneficial, since it furnishes food for the organisms which the fish eat. It might even be a good thing if a number of small creeks were kept sufficiently polluted to raise large amounts of blood worms. According to Walker *et al.* (8), these would at times let loose in great numbers and get down to the larger streams to serve as food for large numbers of fish. The difficulty in this scheme is to keep these creeks sufficiently polluted to feed the worms, but not so polluted as to cause odor complaints or complaints from farmers who want to use the water for their cattle.

If a plant discharges directly into a small but popular fish stream, the conditions are naturally worse and it may become necessary to treat the waste more or less completely, the degree of treatment depending on the minimum volume of dilution and the rapidity of the flow in the stream. It is probably safe to say that the dissolved oxygen in a fish stream should not for any length of time during the day be lower than 4 p.p.m., even under dry weather conditions, and that the average for the 24 hours should always be over 6 parts per million. Furthermore, no large amounts of coarse suspended matter should be discharged.

(2) Flow Equalizing Tanks.—The use of such tanks, with or without aeration, may often be found desirable, both where the waste goes to a stream and where it goes to a city sewer. Aeration will keep the waste from becoming septic and will also satisfy any immediate oxygen demand.

(3) Septic Tanks.—These may be very useful in spite of all the bad things which have been said about their use with dairy wastes. When all strong wastes are removed, the proportion of alkali (from cleaners) to milk sugar becomes much greater and this gives the septic tank an opportunity to work, especially if the pounds of B.O.D. loading per unit volume of tank capacity is kept within the limits used for domestic wastes and the tank is properly seeded initially. Under these conditions, good reductions in fat, and suspended matter, and from 30 to 50 per cent reduction in B.O.D. may be expected. The tanks must be tight and vented to a chimney or some other convenient way. Barritt (7) has shown that anaerobic treatment of dilute wastes may be beneficial both on the acid and on the alkaline side.

(4) A Septic Tank Followed by a Mechanical Aerator.—This system is being used in one of our plants. It gives about 50 per cent reduction in B.O.D. on a strong and very variable cheese plant waste.

The aerator appears to take care of the odor. The plant discharges to a dry creek, the only dilution being supplied by the cooling water from the plant. Complaints have been eliminated by the use of the aerator although the waste still is very strong and is causing abundant fungus growth in the creek.

(5) A Septic Tank or Souring Tank and a High-Rate Filter.—This system has been recommended by Halvorson (10) for use on creamery waste. We have tried several combinations of septic tanks with high-rate filters but have never tried the scheme exactly as reported by Halvorson. The system has definite merit, however, if it were possible to combine storage tank, primary settler, secondary settler, and sludge digester in one tank. Halvorson did not get exceptionally high B.O.D. removals per unit volume of filter but his system as a whole did good work on a difficult waste.

(6) Trickling Filters.—Various types of filters have in general been found quite satisfactory in treatment of dairy waste. Some of our experiments will be discussed later in detail. We operate several high-rate tile filters (Halvorson). The B.O.D. removal is good, but not so much as we expected. Of the several old type conventional trickling filters which we have, at least two are giving satisfactory service. The others need improvements, unless our new waste-saving technique will make them superfluous.

(7) The Chemical Precipitation-Activated Sludge Process (Guggenheim).—This process is used in two of our cheese plants, one at Glen Karn, Ohio, and one at Marshall, Indiana. Since great interest has been shown in these plants, more details will be given later. Eldridge (9) has also tried this process and found it to be highly satisfactory.

(8) The Activated Sludge Process.—This has been quite successful on dairy waste, both here and abroad. There are at least two commercial plants operating on dairy wastes in this country, one at New Bremen, Ohio, and one at Sommerset, Pa. The New Bremen plant has been operating quite satisfactory for several years. It appears somewhat expensive to operate because it uses a great deal of air and lime. The New Bremen plant is a good demonstration of the possibilities of the activated sludge process in the dairy industry, since this plant receives all kinds of dairy wastes and has a very variable load.

Experimental Work with Tin Can Filters

A great deal of work has been done on trickling filters in the last several years. Evidence seems to indicate that by the use of recirculation and continuous flow, and possibly double treatment, higher loadings can be used than were previously thought possible. It is by no means clear what constitutes the most economical construction and method of operation for a given waste. Dairy wastes, in particular, require a coarse filter material in order to avoid clogging; at the same time, plenty of surface area is required for biological growth. It was

thought, therefore, that empty evaporated milk tin cans might be a suitable medium. Unlimited quantities of such cans are available everywhere at no cost except for collection, punching both ends with a large hole, and putting them into a suitable bin or silo, with drains in the bottom and a distributor on top. The cans rust to some extent but the biological coating seems to protect them so that they stand up remarkably well. Since rusting is an oxidation and since dairy waste is highly reducing, one would expect some protection from the organic material. Quart size oil cans may be better than evaporated milk cans and are being used in our latest units.

(1) *Experiments with Tin Can Filters, 2 ft. Diameter and 6 ft. Deep.* —In some preliminary experiments in Baltimore in April, 1937, we used four tin can filters, 2 ft. in diameter and 6 ft. deep. Motor driven, finned discs were used to get good distribution of the liquid on top of the filters. These filters were run at four different rates of flow for about a month. The waste treated was a mixed dairy waste with a

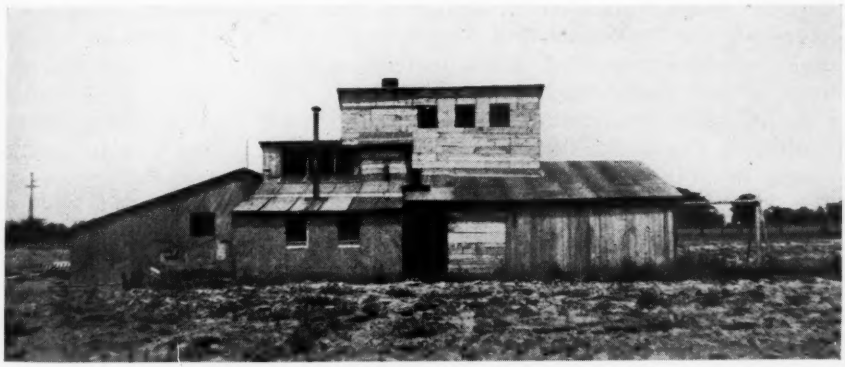

FIG. 1.—Sealtest, Inc., Research Laboratories Experimental Plant for Dairy Waste Disposal at Wellington, Ohio.

generous proportion of cottage cheese whey. Sufficient storage space was provided to get 24-hour operation on fresh waste without recirculation. No settling tanks were used. The rates of flow were 0.25, 0.5, 1.0, and 1.5 g.p.m., corresponding to 5, 10, 20, and 30 m.g.d. per acre. The filters were not run long enough to permit definite conclusions. They all gave from 30 to 50 per cent reduction in B.O.D. without settling, with high B.O.D. removal per unit volume of filter. The experiments were then moved to Wellington, Ohio, where we have gradually built a small experiment station for waste disposal work. (Fig. 1.) The same four filters were set up with four different kinds of cans—7 oz. rusty cans, 14 oz. rusty cans, 14 oz. bright cans, and 7 oz. bright cans—in order to see if the size of the can or the condition of the surface would affect the results. The filters were followed by settling tanks giving about 1 hour retention and with continuous samplers for 24 hour sampling. The four filters were run with approximately the same rate

of flow of 1.2 gallons per minute. The smaller cans were 2½ in. in diameter and were 2⅜ in. tall. They had square holes punched in both ends about 1.4 inches square. There were about 1,570 cans in a filter (18.8 cu. ft.), giving a total exposed surface of about 530 sq. ft., if both inside and outside of the cans are considered. The larger cans were 3 in. in diameter and 3⅞ in. tall with holes 1.5 by 1.5 inches. There were about 720 cans in the filter (18.8 cu. ft.) representing a surface of 475 sq. ft. There was consequently no great difference in the available surface but it might be expected that the smaller cans would give better distribution.

The results of the tests (summary of all results, Table I) showed good B.O.D. removal per unit volume of trickler, but unsatisfactory effluents. There were no marked differences in B.O.D. reduction for the four units under the conditions under which they were tried. The purpose of comparing bright and rusty cans was to find out if the presence of a rusty, rough, iron surface had any particular advantage over a bright tin surface. It was found all through these experiments that the filters were quite irregular in their performance. This may have been due to the fact that they were fed with waste from a souring tank (pH 5.6) without dilution, instead of directly with fresh waste; but it is most likely that the waste was entirely too irregular in strength and that some preliminary dilution would be highly desirable. After a while, it was decided to try two units in series. This was decidedly successful in improving the B.O.D. reduction. The results are given in Series *A*, Table I. We then tried three units in series and at the same time changed to fresh raw feed (pH 6.0) without any souring and have obtained excellent results with a rate of flow of 0.8 g.p.m. This flow corresponds to 16 million gal. per acre per day on one trickler or about 5.3 million g.p.a.d. if all three tricklers are considered. The average B.O.D. removal for the three units of 7.0 lbs. per day for 56 cu. ft., 0.12 lb. per cu. ft., shows excellent efficiency.

The rate of flow was then increased to 1.7 g.p.m. or 34 million g.p.a.d. per unit or 11.3 million g.p.a.d. for the three units. The results are given in Series B_2 in Table I. It will be seen that the average B.O.D. removal was increased to about 0.20 lb. per cu. ft. of filter. At the same time the average temperature was down to 56° F. The final effluents were quite poor, so this loading was obviously too high, at least for the time of the year and under the prevailing conditions. The rate of flow was, therefore, cut back to 0.9 g.p.m. and run that way during January, February, March, and April, Series C_1 Table I. The average removal was 0.13 lb. per cu. ft., as before with 0.8 g.p.m., but the average percentage removal was only 73. It is quite likely that this was due to the prevailing low temperature, which prevented the filters from getting back to proper biological equilibrium. In series C_2 Table I (May) the temperatures were higher, the average lb. B.O.D. removal increased, but the average per cent removal remained the same. The next step will probably be to double the rate of flow, but use 50 per cent recirculation.

TABLE I

Average Values for Sampling Periods

Number Sampling

TABLE I

		Number of Samples	Sampling Period From to	Flow G.P.M.	Average Values for Sampling Periods							B.O.D. Removal Lb./cu. ft.
					Temp. ° F.			pH		5 Day B.O.D.		
					Atmos.	Raw	Eff.	Raw	Eff.	Raw	Eff.	
No. 1	Trickler—7 oz. cans	8	8–11/9 –3	1.3	80	80	78	5.3	5.4	1100	670	0.35
	(Rusty)—Raw waste	5	9–10/9 –28	0.9	64	71	70	5.5	5.6	801	612	0.11
No. 2	Trickler—14 oz. cans	8	8–11/9 –3	1.4	80	80	78	5.3	5.6	1100	711	0.34
	(Rusty)—Raw waste	5	9–10/9 –28	0.8	64	71	70	5.5	5.7	801	633	0.11
No. 3	Trickler—14 oz. cans	8	8–11/9 –3	1.1	80	80	78	5.3	5.6	1100	700	0.28
	(Bright)—Raw waste	5	10– 1/10–15	1.0	58	63	64	5.4	5.6	634	365	0.17
		5	9–10/9 –28	0.8	64	71	70	5.5	5.7	801	602	0.10
No. 4	Trickler—7 oz. cans	8	8–11/9 –3	1.2	80	80	78	5.3	5.4	1100	716	0.29
	(Bright)—Raw waste	5	10– 1/10–15	1.1	58	63	64	5.4	5.6	634	367	0.20
		5	9–10/9 –28	0.8	64	71	70	5.5	5.9	801	614	0.10
Series	Trickler No. 2—From Raw	5	10– 1/10–15	1.5	60	64	64	5.4	5.6	634	351	0.26
A	Trickler No. 1—Eff. from No. 2	5	10– 1/10–15	0.8	60	64	64	5.6	5.7	351	235	0.06
Series	Trickler No. 3—From Raw	5	11– 2/11–15	0.8	49	59	59	6.0	6.5	827	481	0.20
B_1	Trickler No. 2—Eff. from No. 3	5	11– 2/11–15	0.8	49	59	57	6.5	6.8	481	306	0.10
	Trickler No. 1—Eff. from No. 2	6	11– 2/11–15	0.8	49	57	55	6.8	7.0	306	100	0.10
	No. 3, 2 and 1 combined											0.12
Series	Trickler No. 3—From Raw	5	11–16/12–22	1.7	30	56	56	6.3	6.5	878	692	0.19
B_2	Trickler No. 2—Eff. from No. 3	5	11–16/12–22	1.7	30	56	56	6.5	6.7	692	560	0.15
	Trickler No. 1—Eff. from No. 2	5	11–16/12–22	1.7	30	56	56	6.7	6.8	560	364	0.17
	No. 3, 2, and 1 combined											0.20
Series	Trickler No. 1—From Raw	17	1–28/4 –24	0.9	41	61	58	6.9	6.9	892	520	0.21
C_1	Trickler No. 2—Eff. from No. 1	17	1–28/4 –24	0.9	41	58	58	6.9	7.0	520	378	0.08
	Trickler No. 3—Eff. from No. 2	17	1–28/4 –24	0.9	41	58	58	7.0	7.1	378	239	0.08
	No. 1, 2, and 3 combined											0.13
Series	Trickler No. 1—From Raw	4	5–18/5 –26	0.9	66	70	68	6.9	6.9	1058	790	0.15
C_2	Trickler No. 2—Eff. from No. 1	4	5–18/5 –26	0.9	66	68	68	6.9	7.0	790	518	0.16
	Trickler No. 3—Eff. from No. 2	4	5–18/5 –26	0.9	66	68	68	7.0	7.2	518	308	0.12
	No. 1, 2, and 3 combined											0.14

In future commercial units for series filtration, it may be most economical to build the units concentrically. The center part of the unit may be used for a roughing stage at very high rates of flow per unit area and the outside parts, where equal distribution is easier, can be used for one or more final steps. A rotary distributor could easily be built with several rotating concentric head tanks in the middle and a distributor arm from each tank and an overhead inlet from each pump to each tank. The pumps could all be driven by one motor in order to save power. The concentric construction would, save a lot of outside walls, since no definite walls would be required between each section. Only the bottom drains would have to be separate for each section.

(2) *Experiments with Other 2 ft. Diameter Tin Can Filters of Various Depths.*—At the same time as the above experiments were being made, several other filters of various depths were tried. Three units, 2 ft. in diameter and 2 ft. deep, in series with small settling tanks between each step, were tried. They did not give any better results than one simple 6 ft. unit. This multiple unit gave us considerable mechanical trouble, with consequent poor distribution of the liquid, so it is thought that the whole experiment should be repeated. A unit 12 ft. deep and 2 ft. in diameter was also tried. Because of the great depth it was felt that forced draft might be a help. Consequently, the filter was closed on top and a small fan was used to supply a slight draft downward. The average removal at 1 g.p.m. was 51 per cent or only slightly better than the average for a 6 ft. unit (47.4 per cent) run side by side on the same waste at almost the same rate of flow (0.9 g.p.m.). Two 6 ft. units in series for the same period gave an average reduction of 64.4 per cent. It is possible that with higher rates of flow, better draft, and some recirculation, the 12 ft. unit would show up to better advantage.

(3) *Experiments with Tin Can Filters 4 ft. in Diameter and 12 ft. Deep.*—Two semi-plant scale units of 4 ft. diameter were recently installed. In these, quart oil cans, punched in top and bottom, were stacked on top of each other in orderly fashion so as to permit free passage of air from top to bottom. Both units are closed on top, but one has a short chimney for natural draft, while the other has forced draft. These units have been slow in getting started, probably because they were fed full strength waste to begin with. The results to date are summarized in Table II under No. 5 and 6. There seems to be no advantage in forced draft from the point of view of efficiency, but there is some advantage as far as odor and flies are concerned. These filters are not yet doing the work per acre or per cu. ft. done in the same B.O.D. range by the 6 ft. units with the smaller cans just thrown in without arrangement. It is much too early, however, to draw any definite conclusions.

(4) *Results with a Commercial Size Tin Can Filter.*—An octagonal tin can filter of about 300 sq. ft. top area has been in operation at Wel-

TABLE II

	Number of Samples	Sampling Period From to	Flow G.P.M.	Average Values for Sampling Periods							B.O.D. Removal Lb./cu. ft.
				Temp. ° F.			pH		5 Day B.O.D.		
				Atmos.	Raw	Eff.	Raw	Eff.	Raw	Eff.	
Filter No. 5, 150 cu. ft., 4 ft. by 12 ft. natural draft	6	4– 7/5 –18	4.0	53	62	62	6.8	6.8	897	672	.07
	3	5–19/5 –26	2.4	67	71	69	6.8	6.9	1103	453	.12
Filter No. 6, 150 cu. ft., 4 ft. by 12 ft. forced draft	6	4– 7/5 –18	4.0	53	62	61	6.8	6.8	897	637	.08
	3	5–19/5 –26	2.4	67	71	71	6.8	6.9	1103	477	.12
Filter No. 8, Triple unit, 2 by 2 ft	17	1–28/4 –24	0.9	41	61	58	6.9	6.8	892	528	.13
Filter No. 9, 2 ft. by 12 ft. forced draft	13	3–22/5 –26	1.0	55	65	63	6.8	6.9	932	460	.15
No. 10 Disk Aerator. Area—1000 sq. ft.	11	9– 1/10–12	2.9	68	71		5.3	5.8	747	637	
	8	1–28/2 –12	0.5	31	59	50	7.1	7.3	909	333	
	7	11– 2/11–16	0.25	30	56	44	6.3	6.8	878	254	

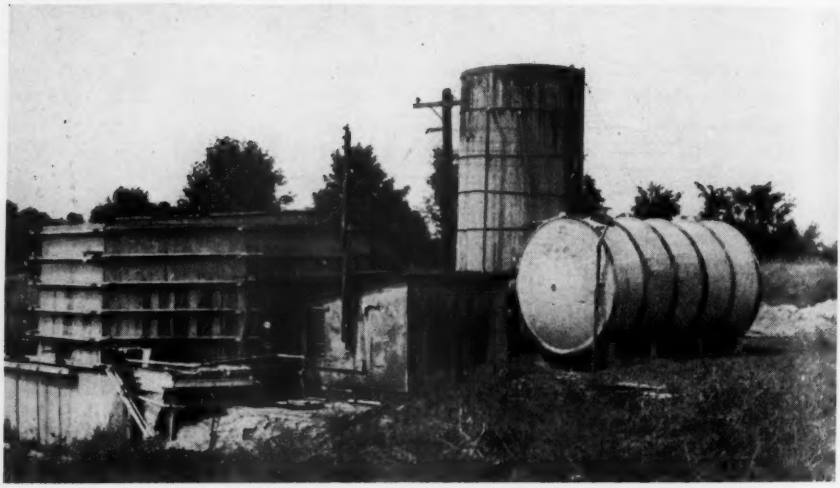

FIG. 2.—Commercial Dairy Waste Disposal Plant at Wellington, Ohio (Telling Belle Vernon Company).

lington for about two years (Figs. 2 and 3), but it was only recently filled with cans to the 4 ft. level and a distributor installed which actually utilizes the whole surface. This filter is arranged in series after a tile filter (Halvorson type) which is 8 ft. in diameter and 8 ft. deep (Fig. 4). The results of analyses of samples from April 20 to May 26

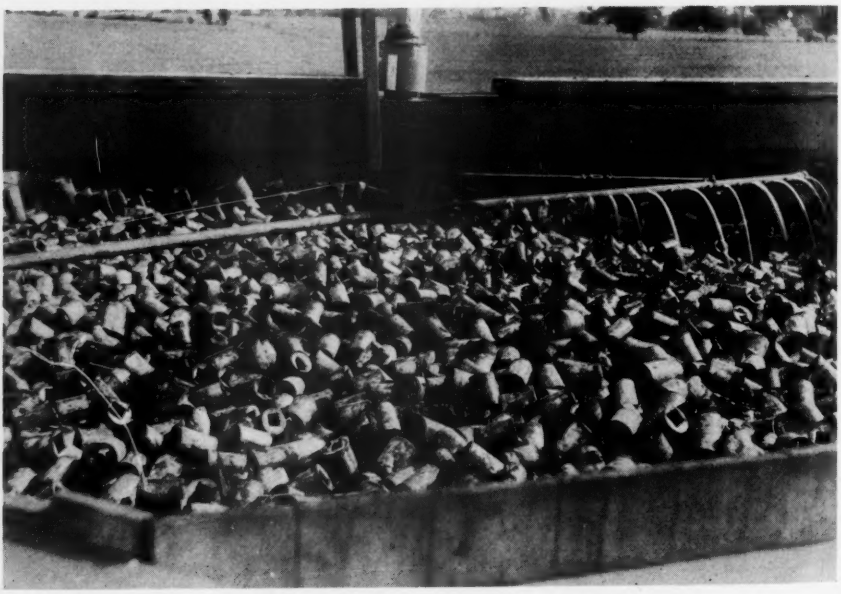

FIG. 3.—Top view of large can trickler at Wellington, Ohio.

are given in Table III. Final effluents are very satisfactory, but the removals per cu ft. not so good as with the small filters. The can filter alone will probably remove up to 40 lb. B.O.D. per day if it is given the

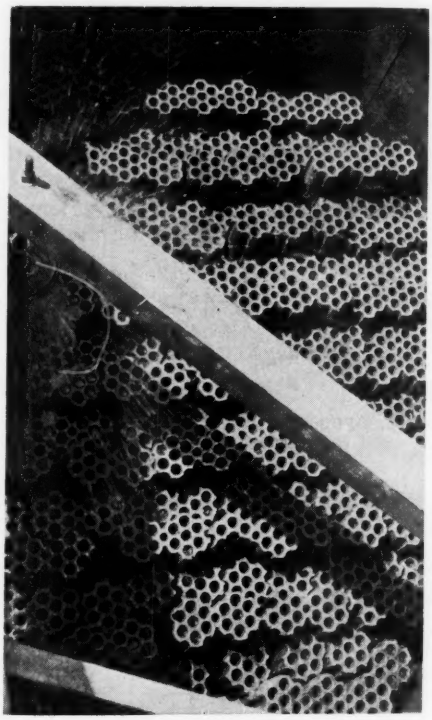

FIG. 4.—Top view of tile trickler at Wellington Ohio.

TABLE III.—*Wellington, Ohio—Operation of Tile and Can Filters in Series*

Date	Influent Mixture		Tile Trickler Effluent 500 Sq. Ft.—400 Cu. Ft.			Can Trickler Effluent 300 Sq. Ft.—1200 Cu. Ft.			Overall Reduction Per ct.
	Vol. Treated Gal.	B.O.D. P.P.M.	B.O.D. P.P.M.	B.O.D. Reduction Per ct.	Lb./ Cu. Ft.	B.O.D. P.P.M.	B.O.D. Reduction Per ct.	Lb./ Cu. Ft.	
Apr. 20	10200	720	480	33.3	.051	0	100	.034	100
24	10800	700	410	41.4	.065	190	53.6	.017	72.9
May 18	8700	700	350	50.0	.064	0	100	.021	100
19	13900	760	430	43.4	.096	40	90.8	.038	94.7
25	10800	760	380	50.0	.086	40	89.5	.025	94.7
26	14400	490	180	63.3	.093	40	77.5	.014	91.8
Avg.	11500	688	372	46.9	.076	52	85.2	.025	92.3

opportunity. This corresponds to 30 cu. ft. per lb. B.O.D. After awhile we shall put the can trickler ahead of the tile trickler in order to see what it really is able to do. The feed is 20 g.p.m. or about 4.1 million g.p.a.d. Recirculation is used from 8 to 16 hrs. per day.

The tile trickler shows up very good on the basis of B.O.D. removal, since it is removing as many pounds as the can trickler, with only one-sixth the top surface area and one-third the volume. This would be expected since it is working on a raw waste with a higher B.O.D. A real comparison can be had only after the two have been switched around. It should be noted that the influent mixture to the tile unit is not really the raw plant waste. It consists of a mixture of raw waste, recirculation from the large can unit, and also some effluent from the small experimental units. The raw waste analysis given for the small experimental units is more nearly representative of what originally comes from the milk plant.

Experimental Work with a Rotating Disk Aerator

In an attempt to find out something more about the nature of the biological purification process, a disk aerator was built of 4 ft. diameter sheet metal plates mounted on a shaft, as indicated in Fig. 5. The

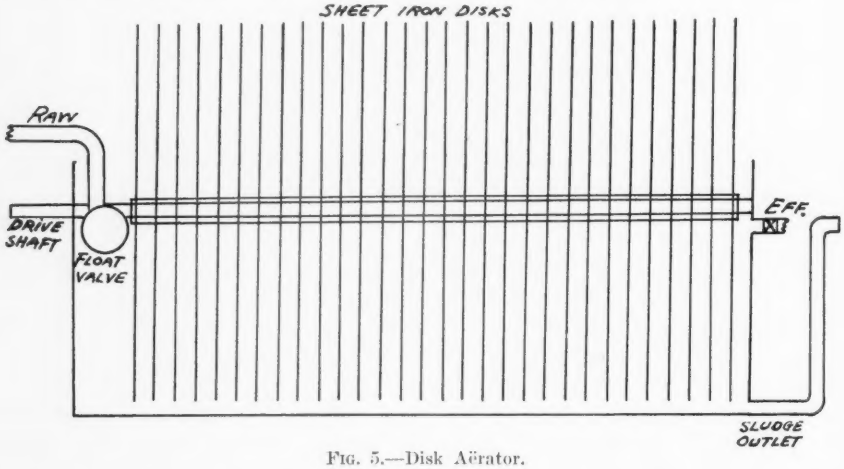

Fig. 5.—Disk Aërator.

disks were rotated slowly, half submerged in the sewage in the tank. We thought it possible to find a speed of rotation which would give a liquid film of the right thickness, and the right amount of aeration to get exceptionally efficient purification. The disk aerator had about 1,000 sq. ft. of surface exposed, which is about double that of the surface exposed by one of the 2 ft. by 6 ft. can units. The unit was operated at various rates of flow and various speeds of rotation until it finally broke down. The average results are shown in Table II. The unit had a very rich growth of fungus all over the plates, but it never

did give very excellent reduction. Neither did it show very good B.O.D. removal per unit area exposed, as compared to the tin can units. Still there should be good possibilities in the development of a unit of this type, especially if a certain amount of recirculation is used. Many types of aerators and contact arrangements have already been tried, but this method should be particularly suited for experimental work since it is very flexible. From a practical point of view, it might be better to have a slowly revolving perforated drum filled with tin cans, since any kind of disk which would stand up would be rather expensive. Very complete wetting of the cans could be obtained in this way, which should mean complete utilization of the available metal surface.

Rapid Flow Tile Filters (Halvorson Type)

As mentioned above, one of these tile filters of 8 ft. diameter and 8 ft. depth, is operating at Wellington, Ohio (outside view Fig. 2, top view Fig. 4). Some results are given for April and May 1938 in Table III. This filter has been in operation for several years in combination with the tin can unit, but up to May, 1938, the two units were operating from the same feed pump and with the same settling tanks and with common recirculation so that it is quite difficult to say how much credit should be given to each unit. Most of the time the can unit was shallow and had very poor distribution so the tile trickler was probably doing most of the work. From September, 1937, to April, 1938, 44 samplings were made. B.O.D. reduction varied from 19 to 83 per cent with an average of 52.2 per cent. This is equivalent to an average of 45.8 lb. B.O.D. removal per day, corresponding to 8.7 cu. ft. per lb. B.O.D. removed per day, if only the tile trickler is considered. The raw waste had an average of 880 p.p.m., and the effluent an average of 408 p.p.m. B.O.D. The waste passed through a septic tank with an average retention period of about 12 hours before it went to the filters. The raw waste samples were taken after the septic tank. The average daily volume treated (without recirculation) was 13,800 gallons.

Another filter of the same size and type is being operated in a cheese plant at Summitville, Indiana. This plant makes a washed type of cheese. The whey is evaporated and dried, but the cheese wash water goes down the sewer. There is no septic tank but only a small primary settling cone, with a screen, in order to prevent clogging of the nozzle. The unit is, of course, quite inadequate but it has been surprisingly successful in eliminating complaints about the creek. This is rather peculiar since the B.O.D. reduction is negligible on a percentage basis. The results for four days operation are given in Table IV. As would be expected the B.O.D. removed is high for such a small unit but it is quite obvious that more treatment is required in this plant unless they should decide that it would be cheaper to evaporate the cheese washings (in addition to the whey itself) or take them somewhere else to be dumped.

Two more filters of this type were installed at Nunda, N. Y., but shortly after they were installed operations at that plant were cur-

tailed to such an extent that it became unnecessary to operate the disposal plant.

TABLE IV.—*Summitville, Indiana Tile Trickler 8 ft. Diameter by 8 ft. Depth*

12 hr. composite samples taken in proportion to flow

Date	Volume Gal.	Raw Waste			Effluent		Reduction Per ct.	Mixed Effluent * B.O.D. P.P.M.
		Temp. ° F.	pH	B.O.D. P.P.M.	pH	B.O.D. P.P.M.		
May 6.....	11,700	89	6.8	3000	6.9	2800	7	
May 7.....	12,600	89	6.9	3200	6.4	1800	44	900
May 8.....	15,180	96	6.9	2700	6.6	2300	15	480
May 9.....	11,640	93	6.8	2600	6.7	1760	32	800
Average....	12,800	92	6.9	2900	6.7	2170	25	727

* Filter effluent mixed with cooling water.

GUGGENHEIM PROCESS

The Guggenheim Process appears to be a combined chemical precipitation and activated sludge process. It consists first of aeration of the sewage alone and then again after adding lime, iron salts and return sludge. This process was first worked out for city waste and then for dairy waste and the first commercial installation for dairy waste treatment was put into operation at our cheese plant at Glen Karn, Ohio, in September, 1936. It was operated by Guggenheim engineers for five months and several changes were made during that time. Trouble was encountered from time to time in handling large amounts of whey which had to be dumped down the sewer because the roads were in such bad condition that it could not be trucked away for evaporation in the usual manner. Except for the difficulties encountered in handling straight whey, the plant has performed very well since about a month after it was installed.

The plant receives from 20,000 to 40,000 lb. of milk per day. The volume of raw waste varies from about 6,000 to 14,000 gal. per day, the average B.O.D. from 600 to 2,000 p.p.m. except when whey is dumped, when it may go 10 times as high. The B.O.D. load is normally between 50 and 150 lb. per day. The waste is first screened through a perforated metal screen with slots 1/8 in. by 3 in., which takes out a lot of cheese particles. After the screen, the waste enters the storage tank, which is supplied with aeration pipes. The waste is pumped from the storage tank to a constant-head orifice tank, which delivers 1,000 g.p.hr. through another perforated screen (slots 1/16 in. by 3 in.) to the aerated flash mixer. Lime suspension, iron solution and return sludge are added here at a constant rate. The mixture then goes to the four aeration tanks, each giving one hour aeration. After the last tank, the liquid flows to the settling tank, which has about a

2-hour detention, and then to the creek. A float valve is provided, which opens when the level in the storage tank becomes low, and lets the effluent recirculate back to the storage tank. In this way the plant is kept operating continuously day and night. The flow at night is mostly recirculation of effluent. Aeration is provided through distributor pipes. Porous tubes and plates were tried but clogged too fast. There are two blowers, one geared to deliver 50 cu. ft. per minute, the other 20 cu. ft. per minute. They are both needed in the summer but in the winter the larger blower alone is sufficient. Excess sludge is discharged once a day to two lagoons located at some distance from the plant. There is no odor from these lagoons. The plant itself is also entirely free from odors and flies, except that bad odors are developed if the sludge is permitted to go black and acid by discharge of too much whey to the plant.

When the plant operates properly, it gives excellent final B.O.D.'s (below 50 p.p.m.), but it has been handicapped by the frequent and unexpected discharges of whey. The power consumption rate is about 3 kw. About 20 lb. of hydrated lime and 30 lb. of ferric sulfate is added daily, giving a chemical cost of about $1.00 per day. Regular labor may be about 1 hr. per day. In addition to this, possibly 3 hours extra are required once a week for cleaning aerator pipes, etc. No particular skill is required in operating the plant. As a matter of fact, the operators at the Glen Karn plant have been changed three times since it was started.

The first cost of this plant is lower than for a conventional trickling filter installation using 80 cu. ft. per lb. B.O.D. per day, but is higher than for a filter using 8 cu. ft. per lb., assuming that it should be found on further work that such a small volume will continue to give satisfactory results on straight cheese waste with occasional strong whey. If rapid-flow, closed filters with forced draft can be made to operate absolutely without odors and flies, the Guggenheim plant would lose some of its advantages. For both types of units, screens, flow equalizing tanks, and some type of settling tank and sludge disposal, must be provided.

Another Guggenheim plant was put in operation in October, 1937, at Marshall, Indiana, and this also operates on cheese waste. In this plant air lifts are used instead of pumps. The plant is built for a larger volume than we have at Glen Karn and has two blowers, each giving 60 cu. ft. per minute. Part of the air is used for air lifts. This plant is using about the same amount of iron salts but much more lime than the Glen Karn plant. Lime consumption has been running from 75 to 150 lb. per day. The final effluent never was as good as it is most of the time at the Glen Karn plant. We do not yet know the reason for this but suspect that unsatisfactory utilization of the air is to blame. The aeration tanks are quite shallow (4½ ft.) and the holes in the distribution pipes rather large (1/8 in.). The load on the plant averages around 15,000 gal. of waste of about 1,000 p.p.m. B.O.D. during the summer months and this corresponds to about 125 lb. B.O.D. per

day, which is not much more than we have at Glen Karn most of the time. Power consumption rate is about 3.1 kw. Chemical cost at present is about $1.60 per day but we hope to cut this in half by better utilization of the air.

Summary and Conclusions

(1) It now appears practical to prevent milk losses, to collect rinsings, and to dispose of spoiled products, excess skim-milk, whey, and buttermilk, in almost all dairy plants to such extent that no process of sewage treatment will be required. Fine screens and, sometimes, flow-equalizing tanks may be all that is needed in many plants.

(2) Dairy plants have five kinds of waste which may with advantage be treated separately: regular domestic waste; cooling waters; spoiled products or excess supply of skim-milk, whey, or buttermilk; drips, leaks, and first rinses; and alkaline wash waters. The various possibilities for the most economical disposal of each are discussed both as regards utilization as by-products and disposal as waste.

(3) It is pointed out that the septic tank may have a far better chance of being useful in the dairy industry if strong wastes are disposed of separately. The anaerobic decomposition of strong wastes for production of fuel gas is also discussed.

(4) The construction of a treatment plant should be done only as a last resort. If it must be done, we now have several methods available which will give any degree of purification desired.

(5) Experimental work with tin can trickling filters is described. Very good effluents with excellent efficiencies were obtained with three filters in series at 5 million g.p.a.d. and 8 cu. ft. of material per lb. B.O.D. removed per day. These results were obtained without recirculation or dilution but it is felt that the performance can be better stabilized with higher rates of flow and recirculation of effluents. A commercial size unit operating in conjunction with a tile high-rate filter is also giving good results but nothing like the efficiency of the triple experimental unit.

(6) Forced draft appears to be of no advantage for efficiency of operation but it may be of help for elimination of flies and odor nuisances around the filters.

(7) Rapid flow tile filters of the Halvorson type are doing good work and will undoubtedly last longer than the tin can tricklers. The latter are much cheaper, however, and have more surface area per cubic foot of filter material.

(8) The chemical precipitation-activated sludge (Guggenheim) process of waste disposal gives good results at a reasonable cost. It is remarkably free from odors and flies and can be built right next to a milk plant without causing any nuisance. The rapid flow, multi-stage, tin can filter system may be somewhat cheaper to construct and operate. Both systems require screens, equalizing tank, settlers, and means for sludge disposal.

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DISCUSSION

BY CHRISTIAN L. SIEBERT

Pennsylvania State Department of Health, Harrisburg

From the point of view of a State Health Department, it is gratifying to hear from a representative of industry that reclamation of skim milk, whey and buttermilk is practical and economical. The first principle of industrial waste control is conservation and next is regulation of discharge to permit maximum advantage of dilution. Incidentally,—"waste is sinful"! Imagine skim milk, whey or, buttermilk being thrown away to-day in Germany or Italy where foodstuffs are scarce!

It is hoped that this thought of Dr. Trebler can be brought forcefully to the attention of the dairy industry by publicity in trade journals.

With respect to drip savers in milk plants, it is understood that New York City now admits milk from dairies which have drip savers, provided the drippings are colored so that they cannot be diverted for human consumption.

I am intrigued by the idea of a good whey wine and suggest that liberal samples be on hand at the meeting of this Association next year.

It would appear logical that dried or concentrated milk wastes be used for stock and poultry feed. If there are seasonal peaks in production which are not in balance with stock raising, adjustments might be made with the use of wastes from other industries, for instance distillery slop, which have peak productions staggered with those of the dairy industry.

Referring to Dr. Trebler's statement concerning the formerly conventional assumption that 80 cu. ft. of trickler material was required per pound B.O.D. per day, Dr. Max Levine (Iowa) in 1933 indicated

that high rates of application to filters removed as high as 2,560 pounds B.O.D. per acre foot, or a removal of 51.1 per cent, and subsequent sedimentation increased this removal to 4,500 pounds B.O.D. per acre foot, or approximately 89.4 per cent total removal of pollution load by filtration and sedimentation from an applied load of 5,000 pounds B.O.D. per acre foot. This filter loading is equivalent to 10 cu. ft. of trickler material as against the conventional figure of 80 cu. ft. Dr. Trebler states that Muers successfully handled 10 per cent whey on tricklers using only 14 cu. ft. per pound B.O.D. and this was confirmed by Barritt. It is hoped that further developments will prove such rates of treatment successful on a large and practical scale.

Dr. Trebler states that before installing treatment works every plant should be given an opportunity to show what can be done without treatment. *This is fine,* but the dairy industry (like most other industries) makes the mistake of procrastinating and opposing pollution control agencies until court action is involved and then it is usually too late to bargain for control based on conservation, and orders of courts and administrative boards are almost invariably in terms of treatment, not conservation.

To actually evaluate the success of conservation methods, we should apply a yardstick of pounds B.O.D. pollution load per unit of milk processed in a given type of milk processing plant.

Concerning disposal by dilution in the receiving stream,—fish often thrive at the point of fresh discharge but die at a downstream point where oxygen in the stream has had opportunity to be depleted by decomposition of matter in solution or suspension, or in sludge deposits.

Concerning the suggested minimum daily D.O. of 4 p.p.m. in the receiving stream and an average of 6 p.p.m.:—oxygen balance (D.O. minus B.O.D.) would seem a safer and more logical standard since it is a more definite measure of potential pollution load and ultimate effect on the receiving stream.

With respect to flow equalization plus aeration, I would like to know more about actual B.O.D. figures on raw and treated wastes in actual practice before offering an opinion as to the practicability of this.

Septic tanks plus mechanical aeration, as mentioned by Dr. Trebler, providing 50 per cent B.O.D. reduction, is a refreshing revival of old practice but, at least in most instances in Pennsylvania, this degree of treatment would probably not be considered sufficient.

Referring to high-rate trickling filters, I wonder how much of the claimed high efficiency of the so-called Halvorson system is attributable to atomized distribution. High B.O.D.'s are said to have greater avidity for immediate oxygen absorption but if, by recirculation of 6 to 10 times or more, the influent untreated waste is so diluted with settled filter effluent that the B.O.D. of waste applied to filter is down around 200 to 300 p.p.m., instead of possibly 600 to 800 p.p.m., or more, the effect of atomized aeration would seem to be reduced to such extent that it would be nearly negligible.

Investigators of the Department of Health have found that the efficiency of an activated sludge type of plant treating milk wastes at Somerset, Pennsylvania, is ordinarily about 94 per cent in reduction of B.O.D. and they have never found it less than 90 per cent efficient. This treatment includes application of lime for conversion of lactic acid to calcium lactate, which is sold, followed by conventional sedimentation, aeration, final sedimentation, and return of activated sludge.

The cost of bio-chemical treatment vs. trickling filters plus sedimentation, is an important question and is complicated by claims on patents and license fees, which may or may not be sustained. Some engineers who have attempted to determine the true status of these claims indicate that they have not been able to satisfy themselves that basic features of either the bio-chemical process or high rate trickling filtration are protected by patents to the exclusion of the adoption of their general principles. To me, it appears that both of these methods have considerable merit or promise, but I understand that the principal objections to the bio-chemical process are cost of operation and difficulty in disposing of sludge, whereas the common criticism of trickling filters relates primarily to flies, odors, freezing, and inefficiency caused by occasional overloading.

It is regrettable that standard economical, and dependable methods of treatment are not seemingly well established and that there is so much controversy about the respective merits and shortcomings of a few methods, for which their proponents claim most promising efficiencies, but this state of affairs can not be accepted in Pennsylvania as sufficient reason for further delay in the installation of milk waste treatment works. Responsible companies must either abate pollution by closed systems or installation of relatively expensive, large, low-rate treatment works of conventional design, or they must take a chance on the experimental installation of one of the proposed, newer methods of treatment, with approval thereof by the Pennsylvania Sanitary Water Board, as now required by law before construction, made conditional upon performance.

Operators' Reports and Suggestions

W. D. Hatfield

249 Linden Place, Decatur, Ill.

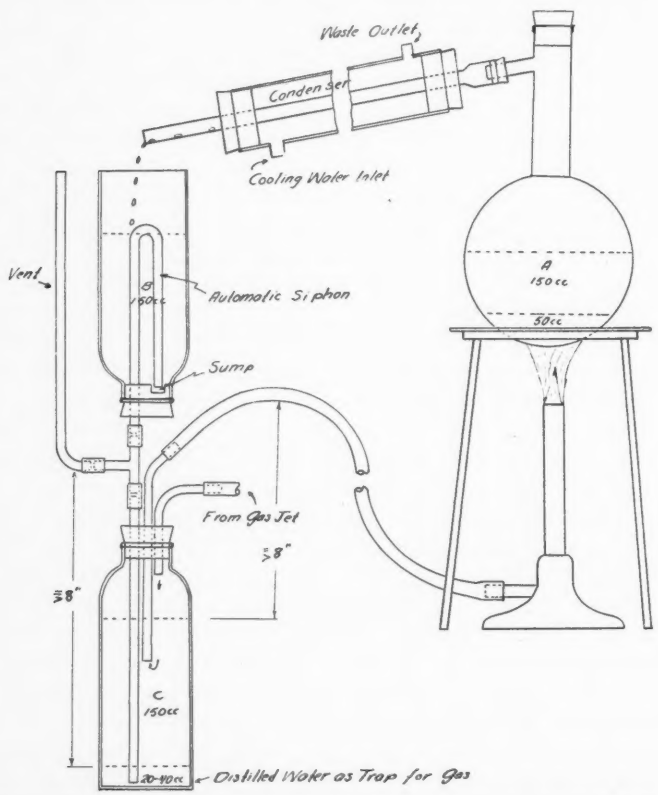
AUTOMATIC SHUT-OFF FOR GAS STILL (USED FOR VOLATILE ACIDS OR NITROGEN DISTILLATIONS)

By J. R. Snell

Harvard Graduate School

The apparatus was designed because many of the tests for volatile acids were ruined because they were not stopped just at the point where 150 c.c. of the 200 c.c. sample had been distilled over.

With the automatic siphon shown in the figure, as soon as 150 c.c. has been distilled over, the distillation is stopped because the gas is



Automatic shut off for gas still (used with volatile acids or nitrogen tests).

cut off by a discharge of the distilled sample from bottle *B* to *C*. The illuminating gas from the gas jet can no longer pass through bottle *C* to the burner because the sample coming down from bottle *B* has made a trap.

The illuminating gas used seemed to have no effect on the sample to be titrated.

In order to keep the automatic siphon at atmospheric pressure a vent is necessary. (See figure.)

To prevent the illuminating gas from escaping through the siphon or the vent it is necessary to place 20 to 40 c.c. of distilled water in the bottom of bottle *C*.

Bottle *B* is made by cutting off the bottom of an ordinary bottle with a red hot electric resistance wire.

This apparatus could well be used for nitrogen tests as well as with volatile acids.

PRIMARY SLUDGE PUMPING *

NORTHERN SECTION MEETING

Edited by W. H. Wisely

Illinois Department of Public Health

That procedure in pumping sludge from separate sedimentation tanks to digesters is of much importance in plant operation, was definitely proven at the Elmhurst meeting. Chairman Sperry, with the co-operation of a number of Northern Illinois operators, assembled a large amount of pertinent data which was presented in chart form (Fig. 1).

Space does not permit us to analyze the data in detail here. However, as you study the tabulation, note particularly the items marked (*), as they are crammed with meaning. Compare similar data from your own records.

Discussion of this material at the meeting was so good that we shall try to present some of the conclusions:

1. Insufficient or delayed pumpage of primary sludge allows digestion to start in the primary tank and results in large chunks coming to the surface. Too frequent or too much pumpage of primary sludge puts much excess water through the digester, resulting in (*a*) waste of heat, (*b*) interference with digestion, (*c*) excessive amounts of supernatant, (*d*) poorer quality supernatant, (*e*) thin digested sludge.

2. The best pumping schedule for each plant must be determined by trial and experience. Many factors, such as (*a*) type settling tank, (*b*) character of sewage, (*c*) working hours of personnel, (*d*) season of year, (*e*) kind of pumps, etc., are involved. For example, note the Geneva data, at which plant a plain, hopper bottom settling tank without mechanism is used.

* From *The Digester*, May, 1938.

Where an operator is in attendance only during the day, common practice is to pump sludge early in the morning and again just before leaving in the late afternoon, the length of pumping, however, varying widely.

3. Rate of sludge pumpage is important. Rates of 35 to 50 g.p.m. appear most common, as there seems to be no "pulling" of sewage through the sludge blanket at these rates. However, higher pumping rates are reported satisfactory at Kankakee, Rockford, Elgin and Chicago Heights, where cross-collectors with flight type mechanisms are employed.

Remember that the rate of supernatant discharge is equal to the sludge pumping rate where fixed-cover digesters with no storage tank are used. This is another reason for pumping slowly at such plants.

4. Operation of sludge collection machinery is important. "Center-scraper" mechanisms are usually operated continuously but "flight" type mechanisms are frequently operated only 30 to 60 minutes before, and during pumping of sludge.

	Kankakee	Rockford	Elgin	Aurora		De Kalb	Chicago Heights	Geneva	Woodstock	Rochelle
				Single Stage	Two Stage					
General										
Type Treatment	Prim.	Prim.	Tr. Filt.	Tr. Filt.	Tr. Filt.	Tr. Filt.	Act. Sl.	Act. Sl.	Act. Sl.	Act. Sl.
Type Sewers	Comb.	Comb.	Comb.	Comb.	Comb.	Sep.	Sep.	Sep.	Sep.	Sep.
Population Served	22,300	85,000	37,000	49,000	49,000	8300	22,800	5000	5600	3785
Sewage Flow (m.g.d.)	2.3	10.1	4.3	6.6	5.9	1.2	2.0	0.8	0.9	0.34
Primary Sludge										
*Type Settling Tank Mech.	Flight	Flight	Flight	Center Scraper	Center Scraper	Center Scraper	Flight	None	Flight	Flight
Total Gallons Daily	8000	33,900	4750	20,600	20,000	4000	5500	5130	3400	5400
*Gal. per Capita Daily	0.36	0.39	—	0.42	0.41	0.48	0.20	1.03	0.61	1.42
*Gal. per m.g. Sewage	3480	3350	—	3120	3400	3330	2750	6410	3780	15,880
*Pumping Rate (g.p.m.)	74	120	150	40	40	35	100	100	40	90
*No. Pumpings Daily	10	12	3	5	5	5	8–9	2	2–3	2
*Ave. Pumping Time (minutes)	10	22	10.5	103	96	15–60	5–10	25	40	30
*Per Cent Total Solids	7.5	6.2	4.1	3.6	3.6	—	3.5	2.1	—	2.1
Per Cent Volatile	63.2	73.7	71.3	65.2	69.2	60.0	69.0	76.8	—	78.6
Sludge Digestion										
No. of Stages	1	2	1	1	2	1	1	1	1	1
Digest. Vol. (c.f. per cap.)	1.9	1.2	—	2.5	2.5	2.7	4.75	4.1	3.0	3.0
Storage Vol. (c.f. per cap.)	1.9	2.75	0	0	0	2.6	4.75	0	0	0
Digestion Temp. (F.°)	98	85–90	89	84	84	85–90	90–96	71	85	85
Gas Prod. (c.f. per cap.)	1.06	1.35	0.96	0.93	1.10	1.3	0.79	1.42	1.05	1.77
Gas Prod. (c.f. per lb. vol.)	7.3	8.9	10.2	10.0	13.0	7.9	15.8	9.0	—	9.0
*% Solids in Supernatant	0.5	0.5	0.1	0.4	0.4	0.3	—	0.5	—	0.2
*% Solids to Drying Beds	8.5	9.10	5.5	6.6	5.7	8.5	7.1	7.1	3.3	2.1
*% Solids, Transfer Sludge	—	5.2	—	—	2.9	—	—	—	—	—

Where there are only 2 or 3 pumping periods daily, flight type mechanisms should be operated sufficiently often and long to prevent "belching" up of chunks of sludge when the mechanisms are started.

5. Accurate sampling and detailed laboratory work on primary sludge is highly valuable. Such data make possible positive determination of digester loading and can be used to excellent advantage in explaining digestion upsets (as Walt Sperry can testify from a recent experience).

A schedule that may work satisfactorily at one plant may be completely out of order in yours. Keep at this problem until you arrive at a pumping schedule that keeps the primary tanks clean, yet minimizes the amount of excess water discharged to digesters with raw sludge.

OPERATING RESULTS AT THE LAGUNA BEACH SEWAGE DISPOSAL PLANT *

By R. D. Woodward

Operator

The Laguna Beach sewage disposal plant is an enclosed plant located within the city limits, five blocks from the business district. It is an activated sludge system, equipped with: One primary clarifier, 30,000 gallons, with Hardinge equipment and Currie air skimmer; two secondary clarifiers, Hardinge, 33,500 gallons each; five Hardinge aerators, with independent motors, tank capacity 51,000 gallons each; one digester with circulating pump and hot water coils; one gas furnace, gas storage tank, one outside burner; two Chicago pumps from the clarifiers; one Chicago screw feed sludge pump; one chlorination pump, used as air clarifier to ventilating system.

The capacity of the plant is 720,000 gallons per day.

Our plant and trunk sewers were built at the same time, the lateral sewers were built later. Therefore, our plant was started with a very small flow, which was taken care of by settling, chlorination and ventilation. The daily average of chlorine for the year 1937 was 12.8 pounds. We were not able to start aeration until the flow reached 30 to 40 thousand gallons per day, as checked by a weir, and Morey and Jones flow meter.

Plant Ventilation.—The plant is ventilated by a large blower driven by a 3 h.p. motor running continuously, which exhausts stale air from one end of each room and draws in the fresh air through ventilators at the other end. The ventilators can be regulated to draw more air from places where the odors are strongest. The foul air passes through a 20 in. pipe to a large chimney or ventilator tower placed on the hillside above the plant. The air is clarified as it passes through the pipe and by 16 chlorinated water sprays. We have found this system to

* Presented at the 1938 Spring Meeting of the California Sewage Works Association.

work very well. We never allow any stale sewage to stand in tanks or flumes. To hold odors down, tanks and flumes should be kept clean at all times.

Plant Construction.—The plant has steel sash windows, light steel ventilators, stamped steel light fixtures. Some of the light fixtures and ventilators have been replaced and we will have to replace more. I believe these items should be constructed especially for a sewage disposal plant of non-corroding materials. I am trying porcelain light fixtures and Everdur metal on one ventilator which cost very little more than the original units. One other problem we have met is that no provision was made in the plant for a shop or storage of supplies. Although we have built two cabinets and bench, these do not take the place of a shop. Every plant should have a shop. We hope to get one soon.

Hardinge Aerators.—These aerators consist of an inverted pump, which pumps the water from the middle of the tank to the bottom through 48 small nozzles. As the water passes the suction point in the pump, by siphon action it takes in air, distributing it in the water. At first the nozzles were pointing to the wall and upward. This arrangement allowed the air to pass out of the water too quickly. The nozzles were then tried pointing across the tank, which arrangement holds the air in suspension much longer. I have lengthened every other pipe or discharge nozzle of the aerators to 3 feet now, which gives still better circulation and air distribution, and allows finer adjustments, increasing the efficiency.

Gas Furnace.—In order not to spoil the beauty of the building, a long vent pipe or chimney was used over the furnace, and has given lots of trouble from condensation running into the furnace and clogging it up, as well as running out onto the floor. We have had to clean our furnace three times, the last time discovering the vent pipe completely corroded. In order not to spoil the looks of the building, the long vent was replaced with Johns Mansville transite pipe doped inside with Inertol, with a trap provided to catch condensation. It is my belief a straight vent through the roof allowing the gas to go out hotter would have been better.

Pumping Plants.—All our pumps are Chicago non-clog, driven by hollow shaft U. S. motors with the line shaft hanging on the motor bearings. This support for the shaft is not very satisfactory. Every time it becomes necessary to remove a shaft, you lose the lineup, as there is only one universal joint, and the motor has to be moved to get the shaft out. We have a great deal of moisture and sometimes a flooded pump, usually caused by sticky check valves. All our line shafts are ball bearing. Ball bearings running in water give a great deal of trouble. Most all ball bearing grease will not withstand submersion in water, so I tested grease in the following manner: I made a beater for a small electric drill, placed one-half lb. of grease in a can with a cup of water and beat it for fifteen minutes. If the water will pour off the grease after this, it will hold in the bearing in water. So

far, only two kinds of grease have been found that will stand this test. Sand gave trouble in one of the pumping plants and resulted in the flooding of the pump and motors. The motors were taken apart, dried out by use of a large air compressor, re-installed and these motors are still running. After removal of sand from the pumps, we found them so badly worn they would pump only about one-half their rated capacity which was insufficient to handle the sewage. New parts were not available. The first pump was taken out, the worn parts welded and machined. This pump is still running. On the second pump we discovered that by machining the lower pump body, we could make a plate instead of welding. The plate was made reversible. When worn, it can be turned over and used again. The worn runner was welded and machined. These pumps have now run a year and a half without further repairs. Not even repacking. We find these pumps should be very closely adjusted. The runner should be set as close to the suction plate as it will run, or about .005 clearance. If this is done, they will not clog.

All of our line shafts are mounted on steel beams, three or four feet long across the wall of the pump room, which rooms are eight feet in diameter and from 15 to 28 feet below ground surface. Being constructed in this way, the bearings are quite noisy. I have overcome some of the noise by mounting the bearings on rubber.

Future Improvements.—Future improvement consist of a new main line connecting the old system to the plant, a new district main line and laterals; and initiation of laboratory control for the plant.

Beautification of the Grounds.—The grounds will be improved with lawns and graveled roadways. A sprinkler system using the effluent will be installed for watering. Some of the effluent may be used for the sprinkling of city parks.

THERMOMETER GADGET FOR USE IN DIGESTERS

By Walter A. Sperry

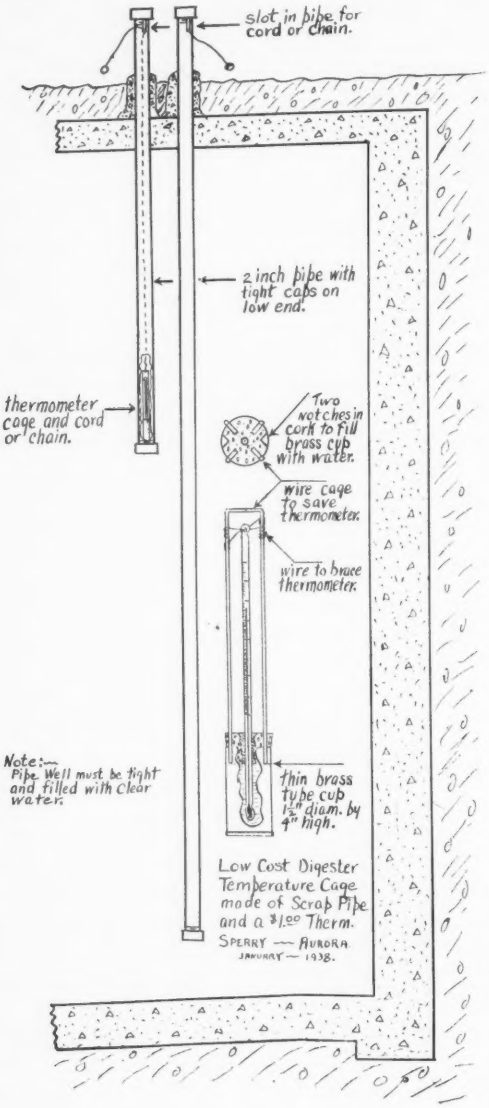
Supt., Aurora Sanitary District

There seems no justification for high priced recording thermometers for use in digesters. The temperatures change too slowly. The familiar "Six Max. and Min." thermometer is too expensive, must be weighted and breaks easily in attempting to work it through the scum layers.

"Doc" Remsburg, of the American Well Works Co., shares the credit for this "Gadget" whose main feature is the thin walled brass cup which retains the temperature until it can be withdrawn and read. It works well both in summer and winter.

The pipe wells must be made up with tight joints and filled with water. The sketch indicates two wells for upper and lower temperatures. This is of doubtful advantage over a single well at mid-depth.

Flexible bronze cable such as used with Venturi meters makes the best cord. The device has attracted some attention and is suggested as good design for digesters. The general details of construction and installation are clearly indicated on the sketch.


slot in pipe for cord or chain.
2 inch pipe with tight caps on low end.
thermometer cage and cord or chain.
Two notches in cork to fill brass cup with water.
wire cage to save thermometer.
wire to brace thermometer.
thin brass type cup 1½" diam. by 4" high.
Note:— Pipe well must be tight and filled with clear water.
Low Cost Digester Temperature Cage made of Scrap Pipe and a 3/100 Therm.
SPERRY — AURORA
JANUARY — 1938.

PAINT POINTERS

By Carl F. Tennant

Supt., Sewage Disposal, Los Angeles County Sanitation Districts

Paint and its application as concerns the sewage treatment plant operator confines itself to the simpler classes of work and the use of ready-mixed paint. It requires no great amount of artistic ability to keep a treatment plant tidy. The more that is known about the behavior and qualities of different paints the more intelligently the operator can purchase the material best suited for the work at hand.

Because a material may possess outstanding qualities for one class of work does not signify that it is suitable for all classes of work. For instance, linseed oil is an excellent outside protection but when used inside turns yellow. And white lead may be used with great success in house painting but cannot be used at the treatment plant because of the corrosive action of sulfide gases upon it. In ordinary paint there is no chemical action between the vehicle oil and the pigment. The pigment is suspended within the oxidizable oil and gives the paint body and wearing qualities but the set of the paint comes entirely from the absorption of oxygen by the oil.

The oils are classed as: drying, such as linseed and Chinawood oil; semi-drying such as corn oil and soy bean oil; and non-drying such as castor oil. Nearly all oils used in paint require processing to make them more suitable. Raw linseed oil is slow-drying but after heating the power of oxygen absorption is accelerated, raw Chinawood oil (tung) dries wrinkly, corn and soy bean oil must be processed to make them suitable and castor oil being a non-drying oil is used in very small amounts as a retarder for highly volatile vehicles. These and other vegetable oils are used by the paint manufacturer in varying combinations to procure just the right film, gloss and speed of drying. Nut oil and poppy seed oil are also used for inside work where white is desired, as is menhaden fish oil.

The thinner recommended by the paint manufacturer should always be used. In varnishes and enamels it is quite possible to use a thinner not compatible with the original mixture and, therefore, loss of time, waste of material and disappointment result.

Driers are admixtures to accelerate the oxidation of the vehicle oil and should be used very sparingly as they shorten the life of the paint film. Driers may be chemical in nature or specially processed oils. Japan drier is a resin drier used preferably in varnish but oil driers are considered superior in oil paint. Litharge is also a powerful drier.

The white pigments most commonly used are white lead (lead carbonate), sublimed white lead (lead sulfate), whiting (calcium carbonate) and zinc oxide. White lead, of course, is unsuitable for use where there may be sulfide gas as it will quickly corrode to a metallic blue-black or gray. Sublimed white lead is more resistant to the attack of sulfide. Zinc oxide if fairly pure is non-bilging but in most instances

contains a little lead due to the ore impurities and cannot always be relied upon not to corrode. The addition of ten to twenty per cent of commercial zinc oxide to white lead helps to prevent the lead from chalking. Barium sulfate is also used as a white pigment.

Black pigments are graphite, lamp black and a long list of bituminous products ranging from albertite to ground coal. Black paint when used outside soon loses its luster and weathers badly. Some black paints will oxidize quickly, rubbing off as a black or brown powder. Black should be used only to a limited extent because it is very somber and gives the plant a dreary appearance. There are blacks on the market known as automotive enamels which retain their luster much longer than plain oil paints.

Aluminum paint is so well known that it needs no recommendation, but this paint has some peculiar characteristics and is so very often misused that a word about its behavior may be in order. To begin with the pigment or powder is not powder at all but tiny flakes or leaves. When the paint is applied these flakes adjust themselves in a compact scale formation presenting an aluminum sheet to the weather. The spreading of aluminum paint is more of a flowing process than that of brushing. Care must be taken to use only the proper amount of powder per gallon as recommended by the manufacturer. If too much powder is used the particles are crowded and do not have room for the proper leafing. Because the aluminum powder actually floats the proper vehicle must be used. The use of the wrong material may cause the powder to lose its buoyancy and, therefore, no leafing or adjustment will occur. After the paint has been spread evenly and the powder particles have adjusted themselves the paint should not be restroked. The paint should be stirred frequently and only a small amount mixed in advance. There are several types of aluminum paint on the market, some more brilliant than others.

Since in paint it is a matter of pigment dispersion in the vehicle oil rather than solubility, thorough mixing is very essential. A hand drill with a quarter-inch rod bent in a closely compressed letter S will save a great deal of time for initial mixing. Frequent stirring of the paint with a paddle while applying will give the surface a more uniform film. Thorough stroking both ways is necessary to obtain an even thickness of the paint film. This should be done with the tip of the brush.

Over new galvanized work a special primer should be used before paint is applied. Vinegar is sometimes used for this purpose but it may be more satisfactory to buy the special primer of correct strength. After the primer has been applied the surface must be allowed to dry before paint is applied. For ungalvanized iron, red lead has no close competitor as an efficient primer. Oxide of iron called barn red is sometimes used but red lead is generally accepted as being superior. The primer is the real life of the paint job and should be carefully applied. The work must be clean and free from foreign substances or rust. If heavy rust is covered over, the corrosion will continue to progress slowly even under the paint film. In the priming of wood

work the paint should be well thinned with turpentine to permit the first coat to soak into the pores of the wood. This provides a root for succeeding coats.

If the job is to be two or three coat work each coat should be slightly off color. If the job is let by contract this may insure getting what was paid for and if you do it yourself this method eliminates the chance of missing part of the work.

Bleeding is the softening of paint when applied over some material that prevents the paint from setting. You may recall having tried to paint over a piece of dipped pipe. Tar or creasote will cause bad cases of bleeding. The remedy is either the use of specially prepared stain killers or a coat of aluminum paint. Paint can then be applied in any color desired.

Peeling is either the result of a poor foundation being provided by the primer, a poor grade of paint or too thick an application. Three thin coats of paint are better than two thick ones.

Blistering is caused by moisture being trapped beneath the paint film or the paint being subjected to high temperature before the oil has set more than skin deep.

Since the oils used in paint are oxidizable and the oxidation of a substance creates heat, rags used in painting will heat to the point of ignition if left wadded. If the rags are to be used again spread them out so that the heat generated may be carried off by the air and no fire will occur.

The counsel of the representatives of reliable paint houses is always helpful and I wish to acknowledge their cooperation. I wish to extend special appreciation of the assistance of Messrs. Williams and Anderson of the General Paint Corporation. When in trouble consult a paint specialist.

EXPERIENCE WITH PAINTS AT THE MARINA SEWAGE PUMPING PLANT *

By Joseph Corrao

Superintendent of Pumping Plants, San Francisco, California

Paints used for protection against the severe corrosive conditions in sewage plants are limited by the materials available. Research work is constantly carried on in the endeavor to develop new materials for this purpose. Several of the more progressive sanitary districts have made progress in solving this problem by carrying out experimental work in their chemical laboratories. In some cases complete specifications for paints with chemical formulae have been produced and are used as standards. The problems of painting can probably be best worked out by a closer combination of effort from the engineer, commitees formed by engineering societies, and the manufacturer.

* Presented at the 1938 Spring Meeting of the California Sewage Works Association.

Due to the fact that the Marina pumping plant, located in the City of San Francisco, has been constructed entirely underground, certain problems of painting have been encountered which have caused considerable concern.

The structure is cylindrical, with a diameter of 55 ft., and extends to a depth of 30 ft. below the ground surface. The walls are 2 ft. thick, and the structure is divided into two main sections, one the dry well composing the pump room, and the other the wet well or sump. There is a separate entrance to each section from the ground level, but no connection exists between the two. The raw sewage enters the sump through a 30-in.-main which is connected to the sewer by means of a drop-down diversion structure. Due to the restrictions set by the Park Commission of the City of San Francisco and the fact that the plant is located in an exclusive residential district, the problem of ventilating presents several difficulties. The ventilation of the plant is accomplished by discharging the air from the machinery room through a grill located at the ground level, and the exhaust gases from the sump are discharged through a hollow stainless steel flag pole 60 ft. high.

Initially, that part of the concrete walls of the sump submerged in the sewage was painted with a bituminous base paint, and that part of the walls not submerged was painted with mill white gloss enamel. The mechanical work such as piping, railings, and valves were painted with dulux machinery enamel. Within several weeks after the plant was put into operation, the mill white paint softened and turned dark brown. It would not harden, and as time went on, the condition became worse and finally the film spalled off of the wall. The coating would harden, however, during shut down periods, but with normal operations it would again soften, especially when the humidity and temperature were high.

The enamels used for painting the metals in some cases were applied with a prime coat of red lead followed by two coats of machinery enamel. In some cases, the metal surfaces were merely given two coats of machinery enamel. The coatings in which the red lead prime coat was used failed within several months, but the coatings applied without the red lead prime coat lasted considerably longer, especially when the surfaces were thoroughly cleaned of mill scale and dirt before application.

The bituminous base paint used on the walls stood up with no apparent marks of failure. The original coating is still intact.

Our attention was immediately concentrated on the reasons for failure and the possible elimination of similar results elsewhere. With this in view, considerable experimenting has been done and a sincere effort made to thoroughly solve our problems. Samples of paints are being constantly analyzed by our City Chemist and are put to trial by placing them in the sump of the Marina pumping plant.

In discussing the subject of painting as applied to sewage works, it might be beneficial to consider a few fundamental characteristics of

paint which will enable those not very familiar with the technical phase of the subject to better understand why they fail in certain conditions.

Pigment.—Pigments constitute the body or aggregate of the paint. They are the major factor in determining the density and also the impermeability. The impermeability is sometimes accomplished by the formation of a hard interlocking surface which is formed by the pigment rising to the surface of the liquid before it hardens. Aluminum and mica perform in this manner.

Vehicles are protected by opaque pigments because they hinder the action of actinic light or sunlight.

Neutralizing decomposition products formed during the process of oxidation while drying and aging of the film takes place is another important function of the pigment.

Rust inhibition is accomplished by some pigments because of their passivity on the surface of the steels and thus they prevent corrosion from taking place even though water and corrosive agents succeed in penetrating to the steel. This action stops, however, if the film is broken. The decorative features of coloring are largely brought about by the pigment.

Binding Material.—That part of the vehicle which furnishes the binder is composed of drying oils and natural or synthetic resins. The term vehicle as used in painting means the liquid medium with which other substances are mixed to form a binder for the pigments and also to permit easy application of the paint. The most important of the oils are linseed, tung, fish and soya. The oils assist in binding the particles of pigment together. This is accomplished by evaporation, polymerization and oxidation which results in hardening of the film.

Linseed oil has been used extensively and dries in the film forming a leathery substance known as linoxyn. This oxidized film is fairly waterproof. Although a certain amount of water passes through this film, no serious effect takes place, especially if a passive pigment is used such as lead; but if the little bubbles formed by the moisture should burst, then rusting or corrosion takes place.

Linseed oil is generally refined by acid and alkali and heat treated to different degrees. The more heat treatment given, the more waterproof it becomes. The oil then is very viscous and hard to brush, but is more water resistant. The heating increases the reactivity of the oil so that when certain reactive pigments are used trouble will be experienced with hardening in the containers.

The heat treatment expels moisture and reduces the amount of oxygen needed for ultimate drying.

Tung oil (china wood oil) is also very commonly used. The oil is never used in a raw state. Tung oil varnish films are more waterproof than are linseed oil films. A combination of tung oil and linseed oil is often used.

Solvents and Thinners.—Primarily, solvents and thinners are used to dilute the paint and render it less viscous, thus making it more easily applicable. The thinner is lost during the process of drying of the

applied paint. When turpentine is used as a thinner it partially polymerizes and becomes an integral part of the dried paint film.

Some of the other things accomplished by solvents and thinners are:

1. Reduction in the consistency of the paint in order to permit proper application by brushing, spraying, dipping and enabling the application of flat finishes.
2. Forming a solvent for the gums, polymerized oils and the driers.
3. Formation of skin and wrinkle effects are greatly reduced.
4. Increases the bonding of films and their penetration.
5. Makes possible the use of highly pigmented paints.

In analyzing the failure of the mill white gloss enamel paint used at the Marina pumping plant it was found to be due to two causes, namely saponification and the reaction of the hydrogen sulfide gas with the lead pigments in the paint forming lead sulfide, which is yellow to dark brown in color, depending on the length of time of exposure.

Paints containing drying oils such as linseed, tung, fish and soya contain variable amounts of fatty acids which combine with the pigment and form compounds called soaps. Both soluble and insoluble soaps are formed.

In painting over concrete, plaster, and brickwork, soluble soaps of sodium, calcium, and potassium may be formed, thus destroying the bonding effect of the paint if not properly controlled. This saponifying action took place quite extensively on the walls of the sump of the Marina pumping plant. This action was aided materially by the moisture in the concrete which was present due to the fact that the structure is underground and many months would be required before the concrete would be thoroughly dry.

The action due to the hydrogen sulfide will be described in the following paragraph.

The main causes for failure of paints in sewage plants are as follows:

1. Hydrogen sulfide gas and sulfuric acid, 2. Grease and oil, 3. Ammonia, 4. Water, 5. Organic life, 6. Sunlight, 7. Mill scale and mechanical damage, 8. Improper cleaning of surface to be painted, 9. Faulty application of paint.

Hydrogen Sulfide.—The reaction of hydrogen sulfide gas with lead pigment of the paint forms lead sulfide which is yellow to dark brown in color and destroys the decorative qualities. Where lead compounded paints are used in conjunction with other paints as top coats the top coats will be discolored.

In analyzing the action of hydrogen sulfide gas, which is by far the most prevalent and difficult aggressor encountered in painting around sewage plants, several interesting facts will be found. Tests made in many laboratories indicate that hydrogen sulfide gas will pass through most of the dried films. Those using linseed oil as constituent cannot

withstand the action of the gas, but the films using tung oil have been more successful in this respect.

Iron or steel painted in an atmosphere of hydrogen sulfide and high humidity are subject to another serious action. The moisture collecting on the surface of the steel work absorbs hydrogen sulfide. The sulfide is oxidized first to sulfurous and then to sulfuric acid. Conditions are constantly changing in these atmospheres, and consequently these acids appear in varied concentrations. There are only a few paint films entirely impervious to their passage; therefore, the acids penetrate to the steel and react with it forming sulfur compounds of iron which may occur as black dust, or if moist, a black slime. As a consequence the film breaks down and the acid attacks the steel with increased effectiveness. The ultimate result is the complete breakdown of the surface painted.

The parts most readily affected are the lower part of frame openings, railings, and panels on doors.

Grease and Oil.—These materials do not of themselves seriously affect the steel work about the plant but, as a matter of fact, protect it. However, when oil or grease become emulsified with water they very effectively destroy the paints they come in contact with. They dissolve the vehicle, soften the film and make it susceptible to mechanical damage thereby exposing the steel to attack by water, hydrogen sulfide, and other destructive agents.

When considering paints for metal work to be used under sewage this action must be seriously considered. The only types of paints that appear to resist this action are the highly resinated phenolic, and resin-tung oil varnish paints.

In general, paints which resist the oils and greases are not very effective against hydrogen sulfide. There are several new but rather expensive synthetic resins on the market which have proved reasonably successful.

Ammonia.—Ammonia is formed in sewage works by the breakdown of proteins by organic life. If the sewage is fresh it may be present only in small quantities and its immediate action will not be serious, but over a long period of time it will destroy the paint subject to its action. The fact that it is of alkaline nature causes the saponification of the fatty acids of the vehicle and so destroys the binder of the film. Caustic soda has the same effect.

Water.—The most common of the destructive agencies is water. There are several ways in which the action of water performs its destructive functions.

When present on the surface before painting, it fills the pores and does not permit the paint applied to come in contact with the material, and therefore does not grip firmly. The vehicle becomes saturated and the other constituents become hydrolyzed causing swelling and loss of strength.

It permits oxygen, hydrogen sulfide, ammonia, and other substances to be conveyed into the film where they either destroy it or make it readily susceptible to damage.

Steel is damaged by this action when the pigments absorbed in passing through the film are electro-positive to the steel and thus cause corrosion. However, some pigments when dissolved are inhibitors of corrosion and others have preventive action, but in these cases the prevention only lasts as long as the pigment is present and the action ceases when dissolved from the film. In the event that corrosion of the steel begins under the film, the adhesive qualities will be destroyed and blistering takes place. When the blisters, or nodules, become punctured there is nothing to interfere with direct action of the water and corrosive elements upon the steel and the action continues unhindered.

Sunlight.—Sunlight combined with the presence of oxygen has an ultimate destructive effect on paints. The process of oxidation is increased in the presence of sunlight. The major phases that take place in drying of paint are (1) the solvent and thinners first evaporate leaving a soft coating, (2) oils then become oxidized to form a hard, somewhat elastic film which oxidizes away as time progresses, and (3) organic compounds become polymerized causing structural changes. In the second step the presence of oxygen is absolutely necessary. The action of sunlight also assists in this phase. Sunlight alone has the predominating influence on the third step; oxygen has no contributing influence.

The evidence of disintegration by sunlight and oxygen is shown by chalking and cracking of the film. These effects are caused by changes in film structure so that the elastic and cementing qualities disappear.

Organic Life.—Some direct effect is caused by organic life, but in temperate climates it can be neglected. The action takes place on the vehicle of the paint. In tropical climates, however, this would cause considerable trouble because the molds found in these climates are destructive. The serious indirect effect caused by molds are those which must be considered. The formation of hydrogen sulfide and ammonia as by-products of organic life is the indirect means that causes destruction because of the oxidation of hydrogen sulfide into sulfurous and sulfuric acids.

Mechanical Damage and Mill Scale.—Mechanical damage due to flotsam in the sewage or abrasion during application of the paint are the most common forms.

The action of peeling of the surface due to mill scale may also be considered in conjunction with this subject. This is a very troublesome cause and considerable study has been given as to possible cures.

As steel lies hot on the cooling tables of the mill, oxygen is absorbed and a number of oxides of iron are formed. This coating is very thin and adheres strongly to the steel. This initial coating cannot easily be removed by wire brushing or scraping. Special means must be used in order to remove this scale. If this scale remains unbroken in fabrication or handling, it acts as an excellent protection, but in practice

this very seldomly exists. The scale is generally cracked and loosened over variable areas. Sewage containing ionizing salts or moisture containing acidulous gases coming in contact with this heterogeneous surface causes it to become loose, and eventually it falls off in flakes. If the surface of the scale were painted it would likewise fall off with the scale.

However, if the cracking of the scale was not serious enough to rupture the paint film the corrosion effect would be inhibited, but with the event of breaking of the film the corrosion will start, causing the result previously described.

The corrosion causes the red, brown, and yellow oxides, hydroxides, carbonates of iron, all of which are readily visible and which appear to be the cause for the failure, but in reality the original black oxide is the cause and is difficult to find.

The relatively thin scales which are formed when rolling steel has been done at low temperatures are more difficult to remove than the thicker ones which are produced by rolling at high temperatures. The fact that modern steels are rolled at higher temperatures than in former years is the reason for the increase in paint failures due to mill scales.

Experiences with weathering steel before painting have proved decidedly unsatisfactory. Although some of the scale may be removed by this process, other disadvantages which occur due to long periods of exposure to weather conditions defeat the practicability of its use. Also the chemical effects on the paint applied after the weathering process generally are injurious.

The method of coating the surface of steel with phosphoric acid washes, commonly known and sold as inhibitors, has met with success in some plants. Although this method has not been used extensively, reports of its use elsewhere seem worthy of further consideration. The action when applied to steel appears to bring it into a passive condition reducing the danger of rust formation and insuring good adhesion of the paint. This method of preparing the surface can be done by applying the solution with a brush, making it practical to use in the field. Care must be taken when using these solutions not to select a paint that will be seriously affected by the phosphor compounds formed at the surface of the steel.

Parkerizing and Bonderizing are other methods used in which phosphoric acid is used. In these cases the metals are given a much more extensive treatment than with the previously mentioned method. The pieces to be treated are dipped in tanks containing the solution. However, the cost of this type of treatment is expensive. The size of the pieces treated is also limited by the size of tanks and facilities available for handling. This method, therefore, can only be used in special cases.

Wire brushing and scraping cause the mill scale to be broken and loosened from the steel. This results in a heterogeneous surface with unsatisfactory conditions for painting, and causes a premature failure.

In preparing steel for painting the best treatment available at present is the complete removal of scale by sand blasting or shot blasting. The prime coat should then be immediately applied while the surface is clean and dry.

Improper Cleaning and Faulty Application.—Improper cleaning of surface before application, adding too much thinner to the paint and applying too thin a coat as the prime coat, allows destructive agents to readily attack the surface painted.

The general precautions which are very commonly known come under this heading and consequently will not be considered in detail.

The difficulty encountered with cement paints is the discoloration. This is due to the soluble lime salts which are formed in setting of the cement. The paints used at the Marina pumping plant were supposed to contain a compound which would reduce this ratio of soluble salts as they formed and thus prevent serious discoloration. However, the theoretical results have not been obtained, and there is considerable change in colors which vary according to the moisture content on the surface.

Conclusions

In the light of the experiences gained at the Marina pumping plant and the results being constantly obtained by experimentation, certain limited recommendations are now possible. The experimentation carried on to date has not been of sufficient duration to warrant recommendation of specific formulae, but the characteristics and results of certain classes of paints used have proved that they are well qualified for certain types of work. It must be remembered, however, that when considering the use of paints that conditions affecting corrosion of metals vary considerably in different localities, and therefore every precaution should be taken to select protective coatings which are designed to meet the conditions in question.

1. *Concrete walls exposed to sewage and gases (no sunlight)*

Bituminous base type of coatings are far more successful than other types. The concrete surfaces must be cleaned thoroughly, and all traces of paint remover when used must be washed thoroughly. Surfaces must be dry before application.

2. *Iron and steel submerged in raw sewage or exposed to gas*

The actions of metals below the surface, especially where the body is moving, are not so severe as might be expected. The greatest difficulty in maintaining the paint on the metal is due to the action of grit and flotsam in the sewage. The metal may even be brightened by the scouring action. Because of the oxygen demand of the sewage this action is probably minimized. Bituminous enamels fortified with high grade synthetic resins have produced favorable results. Constant repainting is required mainly to offset mechanical abrasion.

Two coats must be used and scale must be completely removed before applying prime coat.

3. *Iron and steel surfaces exposed to slightly gaseous conditions*

High grade machinery enamels using the best types of synthetic resins are satisfactory when care is exercised in application of the coatings. The success depends entirely upon the prime coat. With clean surfaces free from moisture, oil and scale, and a prime coat applied not too thin, followed by a second coat of the same paint after complete drying of the prime coat, the results have proved to stand up very well. Care must be given to the drying of the prime coat. If possible, doors and windows should be opened, or other methods employed to increase the supply of fresh air when coats are drying. It will be found that under a slightly gaseous atmosphere the paints will take considerable time to dry and will not last their expected life.

4. *Aluminum paints, exposed to concentrated gaseous conditions, high humidity and without sunlight*

Samples were tried with a large number of aluminum paints using various types of vehicles and also coatings over bituminous paints, and in every case the results were unsatisfactory. The aluminum color continually darkened with a final color of a very dark gray.

5. *Preparing iron and steel surfaces*

The most effective method of removing mill scale is by sand blasting and shot blasting.

Assistance in compiling information for this article was courteously given by Mr. C. L. Cook, city chemist.

Editorial

THE NINE YEAR INDEX

Ten years ago, in October, 1928, the first issue of the SEWAGE WORKS JOURNAL appeared. Each year since then, the final issue has contained a subject and author index. About two years ago, Mr. Emerson began to discuss the desirability of a nine- or ten-year index in 1938, to celebrate the first decade of the life of the JOURNAL, to expedite the search for references, and to serve as a model for future ten-year indexes.

After considerable preliminary work by Mr. Emerson, in which he compiled data concerning the length, cost and method of financing such an index, the question was discussed at the 1938 annual meeting of the Federation. The various possibilities were canvassed, and it was concluded that the index should appear in 1938, but the scope and cost were not fixed. There were two main possibilities, namely that it should be issued as a separate booklet, to be offered for sale at a minimum price, or that it be published in one of the regular issues of the JOURNAL. Fortunately, the latter possibility has been realized, so that now all of the members of the Federation, and all subscribers to the JOURNAL, are being presented with this addition to their sewage works literature. The September issue was available for inclusion of the index because this issue marks the low point in availability of material, and also it antedates the annual index, which for 1938 will appear in the November issue. At first, only the subject index was sent to the printer, but later it was found possible also to publish the author index, which will be a boon to many who wish to trace an article through the name of the author.

The gratitude of the Federation members is due Mr. Emerson for his unselfish devotion in having the cards prepared for the printer. This work proves, as in many previous instances, that he does not retain the post of Chairman merely as a figurehead, but that he is constantly working for the advancement of the Federation and the JOURNAL. May he long remain our Chairman!

F. W. M.

THE ANNIVERSARY BOOK

The announcements that have been made by Mr. Pearse concerning the Anniversary Book now culminate in the news that the book is nearing completion. An advance order blank, included in this issue, offers the book at a reduced price to members of the Federation and subscribers to the JOURNAL.

This book will mark a milestone in the history of sewage treatment, here and abroad. There has never been anything like it in the field of sewage treatment, sewage disposal and industrial waste disposal. Thirty-three chapters have been written according to a plan which sought to emphasize primarily the specific field of the writer and his viewpoint of developments in this field. The topics were chosen, as closely as possible, to cover processes of sewage treatment, disposal of effluents, research in the laboratory and plant, disposal of industrial wastes, and regional or national aspects of sewage disposal. Thus the field is broad, but each contributor has written on the subject which is nearest his interests and activities.

Distinguished men from abroad have contributed chapters. These men include: Dr. H. T. Calvert, of the British Ministry of Health; Mr. John Garner, Past President of the British Institute of Sewage Purification, and loyal friend of the American Federation; Dr. Karl Imhoff, most widely known sewage expert in the world today; Dr. H. J. N. Kessener, the famous Dutch sanitary engineer; Dr. H. Heilmann, experienced German engineer and editor of *Gesundheits-Ingenieur;* and Mr. E. J. Hamlin, the progressive leader of sewage treatment in South Africa.

The list of American contributors is an array of the best-known experts in this country. They write on subjects that will interest all workers in the field of sewage treatment,—from the operator of the smallest treatment works to the director of the most abstruse research; and after all, both of these functions may weigh equally in the scale of values, if each man is conscientious in his duties, honest in his data, and proud of his handiwork.

Therefore we urge you to send in your order for this book on the enclosed postcard. Don't delay, as we may have underestimated the demand for the book, and the edition may soon be exhausted. Mr. Pearse has completed a fine undertaking and he deserves the grateful thanks of all his co-workers in the field of sewage treatment for his accomplishment. Mr. Buffum again shoulders the business responsibilities, as he has so often in the past. He has been urging the publication of this book for years, and now we can appreciate his far-sighted and unselfish interest in the progress of scientific sewage treatment.

F. W. M.

Proceedings of Local Associations

PENNSYLVANIA SEWAGE WORKS ASSOCIATION

Twelfth Annual Conference

State College, Pennsylvania, June 9–10, 1938

The opening session of the Twelfth Annual Conference of the Pennsylvania Sewage Works Association, held at State College, Pa., convened at 9:30 o'clock on the morning of June 9th, President F. S. Friel, presiding.

The Association was welcomed by Dean H. P. Hammond of the School of Engineering of State College. The Dean pointed out that 30–40 per cent of the results obtained at a sewage treatment plant depended upon design and 60–70 per cent upon operation and stressed the importance of the Association meetings.

The first paper was by George F. Appel, who spoke on "Some of the Legal Aspects of Financing Sewerage Projects in Pennsylvania Municipalities." This paper is published in this issue of *The Journal.* W. L. Stevenson discussed Mr. Appel's paper. W. W. Morehouse spoke briefly on the subject of sewer rentals in Dayton, Ohio. The paper was also discussed by C. A. Emerson, Jr.

A business session followed this paper.

The afternoon session was devoted to a so-called "Sewage Works Clinic," conducted by H. M. Freeburn. The following discussions were given:

G. M. Olewiler—"What Can I Do to Reduce Power Bills at My Plant?"
N. S. Chamberlain—"Operating Difficulties at the Farrell Treatment Plant."
W. A. Darby—"Sewage Screens."
G. J. Wiest—"Degreasing Sewage."

At the dinner meeting in the evening Francis J. Myers, Deputy Attorney General of Pennsylvania, spoke on "Pennsylvania's New Stream Pollution Law."

The first paper on Friday morning was by H. A. Trebler entitled "Milk Waste Treatment." This paper is also published in this issue of *The Journal.* Discussions by C. L. Siebert and E. D. Walker followed.

The other two papers which were given were by S. E. Kappe and Frank Roe on "Activated Sludge—Mechanical Aeration vs. Diffused Air," discussed by C. C. Agar; and "Starting a New Sewage Plant" by Frank Woodbury Jones, discussed by W. L. Sylvester.

L. D. Matter, *Secretary*

MARYLAND–DELAWARE WATER AND SEWERAGE ASSOCIATION

Twelfth Annual Conference

Baltimore, Maryland, May 19–20, 1938

The Twelfth Annual Conference of The Maryland-Delaware Water and Sewerage Association was held at the Emerson Hotel in Baltimore, Maryland, on May 19 and 20, 1938. There was a total registration of 203, the largest in the history of the Association.

Following the address of welcome by Mr. Bernard L. Crozier, Chief Engineer of the Baltimore City Department of Public Works, Dr. Abel Wolman spoke on "The Stream Pollution Problem." Dr. Wolman stated that while the treatment of domestic sewage has progressed satisfactorily, the treatment of industrial wastes presents a different picture. More time, energy, research and expenditures are needed to relieve this difficult phase of sewage treatment. Mr. Leon Small, Water Engineer of Baltimore City, next spoke on the design and construction methods used in the Gunpowder Falls-Montebello Tunnel now under construction.

A paper prepared by Mr. William A. Goff, Consulting Engineer, entitled "Construction Methods to Prevent Infiltration in Pipe Sewers" opened the afternoon session of the first day. The joint recommended by Mr. Goff consists of approximately one inch of oakum packing, about 1½ inches of hot bituminous joint and an outside cement mortar fillet wrapped in a muslin cloth tied tight in place. Following this the business meeting was held at which time the following officers were elected:

President: Mr. C. J. Bruce, Supt. Evitts Creek Water Co., Cumberland, Md.
First Vice-President: Mr. A. M. Tawney, Fort George G. Meade, Md.
Second Vice-President: Mr. G. E. Harrington, Dalecarlia Filtration Plant, Washington, D. C.
Secretary-Treasurer: Mr. A. W. Blohm, Baltimore, Md.
Executive Committee: 4 year term—Mr. E. C. Cromwell, Colgate, Md.
Executive Committee: 1 year term—Mr. Elmer St. C. Maxwell, Frederick, Md.

Mr. Walter C. Monroe, Chief Engineer, Anne Arundel County Sanitary District, Glen Burnie, Md., then spoke on "Rubber Pipe for Special Uses." This was followed by a symposium entitled "Glances at Recent Water Works Practice" which was presented by L. H. Enslow, Charles F. Thomas, L. L. Hedgepeth and J. R. Hartley.

In the evening the banquet, floor show and dance were enjoyed by 180 members and friends.

The morning of the second day was opened by Mr. H. G. Turner, State College, Pa., whose subject was "Filter Intestines Minus Coli-Aerogenes." "The Design of Grit Chambers for the Back River Sewage Treatment Works" prepared by Mr. A. Russell Vollmer, Baltimore,

Md., included lantern slides of Baltimore's newest treatment plant structures. Mr. L. C. MacMurray, Resident Engineer, Maryland State Department of Health, in his paper "Co-operation in the Training of Plant Operators" stressed the necessity of intelligent plant control and the value to municipalities of properly trained personnel.

The last session of the conference was opened by Mr. George L. Hall, Acting Chief Engineer, Maryland State Department of Health, with the "Sealing of Abandoned Coal Mines in Maryland." Mr. Hall stated that the streams in the bituminous coal mining regions of the state receive 77,000,000 pounds of sulfuric acid per year from mine openings. Of those mines which have been sealed it has been observed that there is a 72 per cent reduction in acid production. Mr. J. G. Patrick next presented a paper on "Experiments with Ferrisul as a Water Coagulant." "Glances at Recent Sewage Treatment Practice" was a symposium participated in by Mr. W. A. Darby, Mr. W. Donaldson, Mr. A. L. Genter and Mr. J. J. Gilbert.

The meeting closed with a gadget contest the prize of ten dollars being won by Mr. Samuel Claman, Chemist, Maryland State Department of Health, for a self-priming siphon for sewage laboratory work.

A fashion show and tea was provided for the ladies at one of Baltimore's large department stores.

A. W. Blohm, *Secretary-Treasurer*

Reviews and Abstracts

H. W. Streeter

THE B.O.D. OF INDUSTRIAL WASTES

By E. F. Eldridge

Michigan Eng. Experiment Station *Bull.* **78**, 16–19 (1938)

It is pointed out that with reasonable care in manipulation the B.O.D. results obtained with domestic sewage and milk wastes are fairly reliable, but the question is raised as to whether the results obtained with Steffens waste, white water from paper mills, tanning liquors and sulfite liquors have any meaning. For example, a sample of Steffens waste was sent to three different laboratories experienced in B.O.D. determinations. The results reported by these laboratories were 75, 450 and 1400 p.p.m. respectively. A sample of Steffens waste was put up in six different dilutions and all variables were controlled as closely as possible. The values obtained varied from 4000–20,000, the B.O.D. increasing with greater dilution. The duplicate determinations checked, showing that the technique involved was not at fault.

A sample of paper mill white water was put up in three dilutions also with varying amounts of seeding (0–8 c.c. of settled sewage). The results obtained varied from 30–280 p.p.m., the B.O.D. again increasing with greater dilution and with additional seeding.

The apparent cause of these discrepancies is the ratio of the number of organisms (represented by the quantity of seeding) to the available food supply. In the ordinary determination of B.O.D., the same quantity of seed is usually added to the various dilutions, disregarding the amount of food supply present. The number of organisms present should affect the rate of oxygen utilization, especially in the early stages. Therefore, the greater the dilution of the waste the greater will be the ratio of organisms to food supply and the higher the apparent B.O.D.

If the discrepancies are caused by the variation in this ratio it is pointed out that it would be exceedingly hard to standardize the B.O.D. determination when applied to industrial wastes since if a settled sewage is used for seeding no two samples will contain the same number of organisms.

It is pointed out that the total B.O.D. should be the same since it is based on the total oxidizable material present. However, due to an initial lag, or if the time required for total oxidation varies with the character of the waste, it is exceedingly difficult to establish a definite period of incubation.

W. A. Moore

A CONTINUATION OF THE STUDY OF BEET SUGAR FACTORY WASTE TREATMENT

By E. F. Eldridge

Michigan Eng. Experiment Station *Bull.* **78**, 20–37 (1938)

From an extensive study of the treatment of this waste the following conclusions are reached:

1. By using a 40 ft. grit chamber, 11.6 cu. yds. of material were removed per million gallons of waste. The suspended solids removal was 39.6 per cent and the B.O.D. reduction 21.6 per cent.

2. Grit removal and plain sedimentation removed 92.1 per cent of the suspended solids and 42.9 per cent of the B.O.D. By using Steffens waste as a coagulant, these figures were 95.9 and 54.7 per cent respectively.

3. The coagulation period for Steffens and factory waste should be 20 minutes and the settling period 80 minutes.

4. The effluent B.O.D. when plain sedimentation was used averaged about 4 lb. per ton of sliced beets while the effluent from a mixture of Steffens and factory waste was 5.37 lb. per ton.

5. "About 9000 gallons of sludge per million gallons of waste was obtained in both cases. The average moisture content of the sludge from plain sedimentation was 88.5 per cent and from the mixture of Steffens and factory waste was 83–85 per cent."

6. In order to use vacuum filtration of the sludge, it is necessary to pre-treat with 20–30 lb. of lime per 1000 gallons of sludge. Approximately 75 sq. ft. of filter area are necessary per 1000 gallons of waste treated. By using lime pre-treatment a filter rate of 5–6 gallons per sq. ft. per hour was obtained.

W. A. Moore

EXPERIENCES WITH SPECIAL CANNERY WASTES (BEETS, TOMATOES AND SQUASH)

By E. F. Eldridge

Michigan Eng. Experiment Station *Bull.* **78**, 3–13 (1938)

The wastes were first passed through a rotary type screen covered with 40 mesh wire. The screenings were discharged into a pit, the waste flowing into a sump and thence over a weir to the outfall sewer. Two mechanical methods of coagulation were tried in conjunction with chemical treatment, *i.e.*, air and paddles.

A combined red beet-tomato waste after screening was found to have an average suspended solids content of 2,466 p.p.m., and a B.O.D. of 4,045 for a four day run. Since the suspended solids content of tomato waste was later found to average 934 p.p.m., then the suspended solids content of red beet waste should be approximately 2,970 p.p.m. The screen removed 11.4 per cent of the waste. To the waste from the screen, lime was added in amounts varying from 267–1,200 p.p.m., and ferric chloride from 75–100 p.p.m. The mixture was coagulated by means of air and then settled. The reduction in suspended solids amounted to 89.6 per cent, the B.O.D. reduction being 42.3 per cent. This indicates that the larger proportion of the oxygen demand is in solution and cannot be removed by chemical precipitation. Trouble with foaming was encountered in the use of air and it could not be controlled by the use of lime.

In the treatment of tomato waste alone it was found that the average amount of waste per ton of raw product was 295 gallons. The average suspended solids of the waste was 934 p.p.m., and the average B.O.D. 2,900 p.p.m. The screen removed about 8 per cent of the total flow. During the first period when air was used the lime added varied from 200–1,000 p.p.m. The best B.O.D. reduction was obtained when 1,000 p.p.m. of lime was added. With this amount of lime the average suspended solids removal amounted to 88.2 per cent, and the average B.O.D. reduction was 71 per cent. Some foaming appeared when the pH reached 6.8–7.0 but could be controlled. In order to eliminate foaming, paddle mixing was resorted to and lime in amounts varying from 1,000–1,800 p.p.m. was used. Poor settling was obtained and B.O.D. reduction was very low.

In the treatment of squash waste the average flow was about 562 gallons per ton of raw product. The screenings amounted to a large proportion of the flow, the suspended solids being 2,183 and the B.O.D. 4,050 p.p.m. The waste from the screen was treated with lime (350–1,000 p.p.m.) and ferric chloride (100–200 p.p.m.), mixed by means of paddles and then settled for 2 hours. The B.O.D. reduction was small and trouble was experienced with settling.

W. A. Moore

PROGRESS MADE IN MICHIGAN IN THE ELIMINATION OF STREAM POLLUTION BY INDUSTRIAL WASTES SINCE 1929

By L. F. Oeming

Twelfth Annual Report (1938), Michigan Conference on Water Purification

In 1929 legislative enactment in Michigan established a Stream Control Commission charged with jurisdiction over all matters pertaining to pollution in all waters of the State and the Great Lakes. This Commission is both an investigating and an enforcing body, which has pursued a policy of mutual co-operation with industry in attempting to find a solution to the problem of stream pollution by industrial wastes. The major problems which have occupied the attention of the Commission during the past three years concern the pollution by industrial wastes of surface waters which serve as a source of public water supplies. Investigations have centered upon three types of industry whose wastes are chiefly responsible for increased costs and extreme difficulties for water purification plants, namely, the beet sugar, the organic chemical, and the oil industries.

The Beet Sugar Industry.—There are at present 16 beet sugar plants in the State, and the volume of wastes from an average factory is 3,600,000 gallons daily or about 3,000 gallons per ton of beets processed. Present methods of treatment consist of rough screening and sedimentation in large ponds, but this method has been generally unsatisfactory. These wastes impart a marked sugar beet odor to surface water supplies from October 1 to the latter part of December each year. Partial removal of these odors, which are caused by dissolved solids, can be effected by use of activated carbon and in one supply it was found necessary to increase the carbon dosage from a nominal rate of about ¼ grain per gallon to 7 or 9 grains. This removed odors from the water when cold, but not when hot. Five of the twelve sugar plants that operated in 1936–37 are equipped with Steffens houses. This process, which extracts an additional 10 per cent of the sugar in the beet, produces a waste three times as strong as the straight house wastes and with a volume of 120 gallons per ton of beets processed.

The treatment and disposal of the sugar beet wastes has been found to be very difficult, not only from the technical standpoint, but because of the economic position of the industry during the last few years. Under a co-operative agreement between the industry and the Michigan State College Engineering Experiment Station, an experimental plant was operated in 1935 and a full-scale plant was erected the next year in Bay City. This plant provides for grit removal, sedimentation of factory wastes and vacuum filtration of the sludge. A reduction of 95 per cent of the suspended solids and 54 per cent removal of 5-day B.O.D. was accomplished by these means, but it is not expected to relieve the taste and odor problems of surface water supplies. Experiments with the spray drying of Steffens waste, conducted in 1936, were inconclusive. It is felt that further work should be carried on to establish the feasibility of this method. The solution to this problem appears to be either in the utilization of the waste by recovery of by-products or in elimination of the Steffens house process and marketing of the molasses directly.

The Oil Industry.—For the past three years the outstanding pollution problem in Michigan has been the disposal of concentrated oil field brines. A typical analysis shows the following:

Solids	324,000 p.p.m.
Specific gravity	1.22
Calcium	37,500 p.p.m.
Magnesium	6,960 p.p.m.
Sodium and potassium	73,618 p.p.m.
Chlorine	200,000 p.p.m.
Sodium chloride	330,000 p.p.m.
Bromine	1,525 p.p.m.

One of the most damaging effects of brine pollution is the increased noncarbonate hardness it imparts to water supplies. The late Allen Hazen has stated that the chloride radical in excess of 15 to 20 p.p.m. is apt to cause corrosion in boilers and plumbing fixtures. These chlorides are not removed by softening treatments. It is essential, therefore, in oil fields draining to streams used for public water supplies, to keep the discharge of brine wastes as low as possible.

Efforts to solve the problem by ponding the brine were unsuccessful. Light surface soils will not retain the brine in ponds and prevent it from reaching the streams. The brine from one field is collected and pumped to the Dow Chemical Company plant at Midland, where it is processed for bromine and other salts and chemicals and the excess disposed of by regulated discharge and dilution in the Saginaw River.

In the Crystal oil field on the divide of the Grand and Saginaw river basins, it has been found possible to return brine to the underground formations through dry holes or abandoned wells. Quantities varying from 1,000 to 5,000 barrels per day could be disposed of by gravity. After the success of these efforts the operators of Crystal and Vernon fields were ordered to control the brine discharge to streams, and yardsticks for the reasonable use of streams for brine disposal were established. In the Crystal field this reasonable use is exceeded if more than a total of 1,500 barrels per day are shown to be leaving the field, based on computations of stream discharge and chloride concentrations. Under the terms of the Vernon order, reasonable use is exceeded if the concentrations of brine in Kinney Creek are found to be in excess of 4,000 p.p.m. of chlorides for any month.

The Chemical Industry.—The process wastes from the Dow Chemical Co. at Midland are an important factor in the pollution problem in the Saginaw Valley. This company processes 45,000 barrels of brine daily for bromine. Two-thirds of the used brine is stored in ponds and discharged in large amounts at times of maximum available dilution, arrangements being made with the Saginaw and Bay City waterworks so that they can operate on stored water while the slug of brine passes the intakes. The remainder of the brine from which the bromine has been extracted is further processed to obtain various salts and chemicals.

Attempts were made to dispose of the various wastes by controlled discharge into the river, but dilution and stream oxidation were unable to handle the phenols and other taste and odor producing compounds. An experimental biological purification plant was built consisting of two Emscher filters, two trickling filters 5½ feet deep, one using limestone and one coke as media and one 10-foot depth trickling filter with blast furnace slag as media. As it was determined that the phenol-destroying organisms were a common soil bacterium available in the river water, the filters were ripened by the application of river water containing small amounts of phenol.

The results of these experiments have led the company to build a full-scale plant consisting of a clarifier 142 feet deep in diameter and two trickling filters of the same diameter 10 feet deep using blast furnace slag as a media. The waste to be treated amounts to 5½ m.g.d. and contains 20–30 p.p.m. phenol. Judging from the results obtained in the experimental plant, the effluent should have a B.O.D. of 10 to 15 p.p.m., a phenol content under 0.5 p.p.m. and a distinctly earthy odor not phenolic.

Discussion by W. D. Loreaux.—The discussion dealt entirely with beet sugar plant wastes and especially the problem of Steffens waste. It was said that at least three methods of disposal of this waste show promise, namely:

1. Evaporation to dryness. This method may prove costly because of mechanical difficulties and because the waste heat from the plant will only evaporate about 50 per cent of the waste. However, a marketable product, potash, is obtained.
2. Direct application of the waste to land under cultivation. This would provide potash to the sugar beet crop, but transportation costs may be prohibitive.
3. Biological action and stabilization by impounding. This will cause loss of fertilizer value and some stream pollution when the final product is drained into the river. Success depends upon the degree to which stabilization proceeds.

A combination of all three methods might prove practicable:

(*a*) Evaporate to dryness the 50 per cent of the Steffen's waste for which waste heat is available.
(*b*) Transport a portion of the remaining waste to nearby farmland.
(*c*) Biological stabilization of the recarbonated excess waste by long storage and oxidation of the final residue with chlorine during discharge to the river.

R. S. SMITH

SEWAGE PURIFICATION DEPARTMENT, GLASGOW, SCOTLAND, 1894–1937

BY ALEXANDER HUNTER

Pamphlet, 32 pp. with map

This is a summary of the work of the Glasgow Corporation (Scotland) in its sewage disposal problem. The population grew from 77,385 in 1801 to 782,000 in 1903 and is now estimated at 1,150,000 on an area of 40,000 acres. From 1867 to 1888 was a period of report and study. The first sewage works (Dalmarnock) was opened in 1894. Other works were added, until now four are operated. The method of treatment is chemical precipitation, with the addition of trickling filters at Dalmarnock. The outlet is the River Clyde, a tidal estuary.

At Dalmarnock, persulfate of iron was used as a precipitant from 1904 to 1915. Of late, sulfate of alumina and lime have been used. There are six precipitation tanks 465 ft. long by 61 ft. wide and 9 ft. deep, with a total capacity of 10 m.g. The normal detention period is eight hours. Each tank is sludged once a week, by decanting the supernatant liquor. The major portion of the sludge is removed by hand. In 1913, the first section of trickling filter was provided. By 1922, 5¼ acres were developed, with stone graded in three sizes, 4 in., 2½ in., and 1½ in. Water driven distributors are used. Ponding prior to 1920 was stopped by inoculating the filters with *Achorutes Viaticus*. The filters handle about 8¾ m.g. daily, or 169 gal. per cu. yd. The combined effluent averages 22½ m.g.d. Originally, the sludge was filter pressed, followed by heat drying to 20 per cent moisture. In 1911, 32,000 tons were sold. Owing to the scarcity of labor in 1915, the sludge was pumped in a 9-in. main (6¼ mi. long) to the Shieldhall Works and sent to sea by sludge steamer. In 1935, sludge pressing was discontinued. In the 12 months prior to May 31, 1937, 280,000 tons were removed from Dalmarnock and concentrated at Shieldhall to two-thirds its original volume by sedimentation. Compressed air ejectors at 60 lb. per sq. in. discharge sludge into the force-main at rate of 1 ton per min. The working costs are said to be:

Forcemain	1.26 d. (2.5 cents) per ton
Land charges at Shieldhall	1.16 d. (2.3 cents) per ton
Sea disposal	4.7 d. (9.4 cents) per ton
Total working cost	7.12 d. (14.2 cents) per ton

The Dalmarnock sewage is strong, ranging in p.p.m. as follows for three months' averages (see next page):

The Dalsmuir Works serve the western district. They consist of a chemical precipitation plant using lime (4 gr. per gal.) and sulfate of alumina (1.6 gr. per gal.). The precipitation tanks are 8 units, each 750 by 50 by 8 ft., with a total capacity of 18¾ m.g. The detention period varies from 6 to 8 hours. The average flow is 50 m.g.d. Each tank is sludged once a week by hand. The sewage is slightly weaker than at Dalmarnock, the suspended solids averaging around 333 p.p.m.

The Shieldhall Works handle 43¾ m.g.d. with chemical precipitation, using sulfate of alumina and lime. The sewage is similar to Dalsmuir, the suspended solids averaging 320 p.p.m. The Westhorn Works (built in 1926) use the activated sludge process on 1¼ m.g.d. The sludge is lagooned.

	Crude	Effluent of		Combined
		Tank	Filter	
Free amm.	26.8–29.2	26.8–28.6	12.6–13.5	18.9–21.9
Alb. amm.	7.6– 9.3	4.0– 4.2	1.0– 1.3	2.0– 2.3
Ox. cons. 4 hr.	80–101	56–73	16–24	33–48
Chlorine	95–128	98–127	96–128	92–128
Suspended solids:				
Mineral	167–209			
Volatile	197–269			
Total	364–449			

Glasgow owns and operates two sludge steamers, each about 1,550 tons carrying capacity. These make a round trip of 58 miles daily to a disposal field at 540 feet depth. No complaint has ever been received of shore pollution. The total volume of sludge handled last year was 707,529 tons.

There are 330 employees. The sewage rate is approximately 5¼ d. per £ ($2.10 per $100.00), one-half paid by owners and one-half paid by lessees. Improvements planned include mechanical sludge scrapers and continuous flow tanks.

LANGDON PEARSE

THE INTERSTATE COMMISSION ON THE DELAWARE RIVER BASIN

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF HEALTH
HARRISBURG

August 30, 1938

Dr. F. W. Mohlman,
Editor, Sewage Works Journal,
910 South Michigan Avenue,
Chicago, Illinois.

Dear Dr. Mohlman:

I am sending herewith a copy of the Draft of Agreement for the Correction and Control of Pollution of the Waters of the Interstate Delaware River. I thought perhaps you might be interested in this document which represents what to our mind is a forward step in handling matters in the control of stream pollution on inter-state streams.

You will note that this is an Agreement and not a Compact. In the case of New York and New Jersey, an actual Compact was drawn and ratified by the legislatures of the two States. The same method of procedure is proposed for the Ohio River Basin and the Compact is now in draft form ready for final approval by the Commissioners of the eight States in the Basin with the understanding that it will be submitted to the legislatures of these States for ratification.

The procedure on the Delaware River Basin is in direct contrast to that method in that it is a co-operative Agreement between the Health Departments of the four States and no supervisory body is created, as in the case of Compacts. Which method is the better means of handling these problems remains to be seen. One advantage of an Agreement is that it can be modified through suitable action by the Health Departments, which should be far easier than reference to the legislatures of the participating States and would also avoid the delay dependent upon sessions of the legislatures which, in some States, occur only at two-year intervals.

A movement is now on foot under congressional sanction to erect a Potomac River Drainage area as a conservancy basin. At the moment we have no knowledge as to just

how that problem will be worked out, but I believe the thought back of the scheme is that that basin will be used as a demonstration area. Involved in that problem are the States of Pennsylvania, Maryland, West Virginia and Virginia, and the District of Columbia.

These various movements together with those undertaken through the Federal Government seem to indicate a very definite trend in the manner of handling these interstate problems.

Sincerely yours,

H. E. Moses,
Chief Engineer.

NOTICE CONCERNING THE CORRECTION AND CONTROL OF POLLUTION OF THE DELAWARE RIVER AND ITS TRIBUTARIES

A reciprocal agreement to correct and control stream pollution within the Delaware River Drainage Basin has been entered into by the four States of New York, New Jersey, Pennsylvania and Delaware. The agreement was prepared under the auspices of the Interstate Commission on the Delaware River Basin and was formally ratified and made operative by the Department of Health of the four States. In Pennsylvania, ratification was by the Sanitary Water Board in the Department of Health, which is the administrative agency in Pennsylvania having to do with matters of stream pollution.

Minimum requirements, relating to sewage, industrial waste, and other artificial polluting matter, have been established. Because of the variable factors of location, size, character, and flow, and the many varied uses of the water of the Delaware River, the stream has been divided into four zones and the minimum requirements have been drafted to meet the conditions of each zone. No sewage, industrial waste, or other artificial polluting matter may be discharged into the river unless it has been so treated as to produce an effluent which will meet the minimum standards erected by the terms of the agreement.

Edith MacBride-Dexter, M.D.,
Secretary of Health,
Chairman, Sanitary Water Board.

THE INTERSTATE COMMISSION ON THE DELAWARE RIVER BASIN

A Reciprocal Agreement

As Ratified by
Delaware—New Jersey—New York—Pennsylvania

For the Correction and Control of Pollution of the Waters of the Interstate Delaware River

Whereas, A substantial part of the territory of the States of New York, New Jersey, Pennsylvania and Delaware is situated within the Delaware River drainage basin; and

Whereas, The increase in the population of the various municipal areas situated within the Delaware River Basin, and the growth of industrial activity within the Basin, have resulted in increasingly serious pollution of the waters of the interstate Delaware River and its tributaries; and

Whereas, Such pollution constitutes a grave menace to the health, welfare, and recreational facilities of the people living in the Delaware River Basin, and occasions great economic loss; and

Whereas, The control of future pollution and the correction of existing pollution of the waters of the interstate Delaware River and its tributaries is of prime importance to

the people living in the Delaware River Basin and can best be accomplished through the co-operation of the representatives of the people in the Basin, in the States of New York, New Jersey, Pennsylvania and Delaware;

Therefore, the State of New York and the State of New Jersey and the Commonwealth of Pennsylvania and the State of Delaware agree and are bound as follows:

Article I

Interstate Co-operation

Each of the signatory States pledges to each of the other signatory States faithful co-operation in the control of future pollution and in the correction of existing pollution of the waters of the interstate Delaware River and its West Branch from the New York-Pennsylvania boundary line down to the Atlantic Ocean. In order to effect such objects, each of the States agrees to enact adequate legislation, if necessary, to enable each such State so to require the treatment of sewage, industrial waste or other artificial polluting matter as to place and maintain the waters of the aforesaid interstate Delaware River, and of the tributaries thereof just above the confluence with the Delaware River, in the clean and sanitary condition required by the provisions of this agreement. Furthermore, each such State agrees so to enforce the provisions of these requirements, and other supplementary applicable legislation, if any, as to bring about the attainment of the objectives of pollution control and correction in accordance with such reasonable and effective programs as may be determined from time to time by the States in the manner prescribed herein.

Article II

Classification of Zones

It is recognized by the signatory States that due to such variable factors as location, size, character, and flow, and of the many varied uses of the waters of the interstate Delaware River, and its aforesaid West Branch, such as water supply, recreation, navigation, industrial developments, maintenance of fish life, shellfish culture, agriculture, and other purposes, that no single standard of sewage and waste treatment and of quality of receiving waters is practical for all parts of the River. Therefore, in order to apply minimum requirements for the attainment of correction and control of pollution which will be appropriate to the varied factors including the existing and potential quality and uses of the waters, the interstate Delaware River is hereby divided into four zones, to wit:

Zone I.—Zone I is that part of the Delaware River and its West Branch extending from the New York-Pennsylvania boundary line to the head of tidewater at Trenton, New Jersey, and Morrisville, Pennsylvania.

The drainage basin contributory to this zone, excepting part of the Lehigh River Basin, is relatively sparsely inhabited and contains few sewered communities and relatively few industrial establishments producing waste water. The streams draining the area being, in general, relatively clean and of high elevation, are well adapted as sources of public water supplies, after treatment or purification.

The principal uses of the waters of the Delaware River in Zone I are expected to be for water supply after such treatment or purification as may be necessary, and for recreation, bathing, maintenance of fish and aquatic life, agriculture, and for other related purposes.

Zone II.—Zone II is that part of the Delaware River extending from the head of tidewater at Trenton, New Jersey, and Morrisville, Pennsylvania, to a line drawn perpendicular to the channel of the Delaware River from the mouth of Pennypack Creek in Philadelphia, Pennsylvania, to the corresponding point on the New Jersey shore.

The drainage basin contributory to this zone is somewhat more densely populated than that of Zone I, and it contains more sewered communities and industrial establishments.

The principal uses of the waters of the Delaware River in Zone II are expected to be for water supply, after treatment or purification, and for recreation, navigation, maintenance of fish and aquatic life, agricultural, industrial and other purposes.

Zone III.—Zone III is that part of the Delaware River extending from the aforesaid line connecting the mouth of Pennypack Creek in Philadelphia and the corresponding point in New Jersey to the Pennsylvania-Delaware boundary line.

The drainage basin contributory to this zone contains populous metropolitan areas including Philadelphia, Pennsylvania, and Camden, New Jersey.

The principal uses of the waters of the Delaware River in Zone III are expected to be for navigation, industrial water supply, and other purposes.

The water in this zone, however, should be of such sanitary quality that it will not be unfit for use as sources of water supply, will not be harmful to fish life, and will not adversely affect the quality of the waters of the tidal tributaries.

Zone IV.—Zone IV is that part of the Delaware River extending from the Pennsylvania-Delaware boundary line to the Atlantic Ocean.

The principal uses of the waters of the Delaware River in Zone IV are expected to be for navigation, industrial water supplies, commercial fishing, shell fish culture, recreation and other purposes.

In order to attain conditions of cleanliness and sanitation of the waters of the Delaware River which will be consistent with the appropriate existing and future quality and uses of such waters, the following minimum requirements shall apply to the several zones herein provided. It is the purpose and intent of such requirements to apply to artificial (not natural) causes of pollution.

Article III

Minimum Requirements

The Interstate Delaware River:

In order to put and maintain the waters of the interstate Delaware River and its West Branch as aforesaid, in a clean and sanitary condition, no sewage, industrial wastes or other artificial polluting matter shall be discharged into, or be permitted to flow or fall into, or be placed in any respective zone of the interstate Delaware River as herein established, unless such sewage, industrial waste or other artificial polluting matter shall first have been so treated as to produce an effluent which will meet the folowing minimum requirements:

Zone I.—1. Such effluent shall be free of noticeable floating solids, color, oil, grease, or sleek, and practically free of suspended solids.

2. Such effluent shall be sufficiently free of turbidity that it will not cause noticeable turbidity in the water of the Delaware River.

3. Such effluent shall show a reduction of organic substances of at least eighty-five (85) per cent as measured by the bio-chemical oxygen demand, and furthermore, such effluent in no case shall exceed a bio-chemical oxygen demand of fifty (50) parts per million, and furthermore, the discharge of such effluent, after dispersion in the water of the river, shall not cause a reduction of the dissolved oxygen content of such water of more than five (5) per cent. The aforesaid reduction in dissolved oxygen content shall be determined by the average results obtained from dissolved oxygen tests made upon samples collected on not less than six (6) consecutive days from points in the river above and below the point or points of effluent discharge.

4. Such effluent shall be of such quality that the most probable number of organisms of the *Coli Aerogenes* group shall not exceed one (1) per milliliter in more than ten (10) per cent of the samples of sewage effluent tested by the confirmed test, and provided further that no single sample shall contain more than one hundred (100) organisms of the *Coli Aerogenes* group in one (1) milliliter.

5. Such effluent shall be sufficiently free of acids, alkalis, and other toxic or deleterious substances, that it will not create a menace to the public health through the use of the waters of the Delaware River for public water supplies, for recreation, bathing, agriculture and other purposes; nor be inimical to fish, animal or aquatic life.

6. Such effluent shall be free of offensive odors and also be free of substances capable of producing offensive tastes or odors in public water supplies derived from the Delaware River at any place below the discharge of such effluent.

Zone II.—1. Such effluent shall be free of noticeable floating solids, color, oil, or grease, and practically free of both suspended solids and sleek.

2. Such effluent shall be sufficiently free of turbidity that it will not cause noticeable turbidity in the water of the Delaware River.

3. Such effluent shall show a reduction of organic substances of at least eighty-five (85) per cent as measured by the bio-chemical oxygen demand, and furthermore, such effluent in no case shall exceed a bio-chemical oxygen demand of one hundred (100) parts per million, and furthermore, the discharge of such effluent, after dispersion in the water of the river, shall not cause a reduction of the dissolved oxygen content of such water of more than ten (10) per cent. The aforesaid reduction in dissolved oxygen content shall be determined by the average results obtained by dissolved oxygen tests made upon samples collected on not less than six (6) consecutive days from points in the river above and below the point or points of effluent discharge.

4. Such effluent shall be of such quality that the most probable number of organisms of the *Coli Aerogenes* group shall not exceed one (1) per milliliter in more than twenty-five (25) per cent of the samples of sewage effluent tested by the confirmed test, and provided further that no single sample shall contain more than one hundred (100) organisms of the *Coli Aerogenes* group in one (1) milliliter.

5. Such effluent shall be sufficiently free of acids, alkalis, and other toxic or deleterious substances, that it will not create a menace to the public health through the use of the water of the Delaware River for public water supplies, for recreation, industrial and other purposes; nor be inimical to fish, animal or aquatic life.

6. Such effluent shall be free of offensive odors and also be free of substances capable of producing offensive tastes and odors in public water supplies derived from the Delaware River at any place above or below the discharge of such effluent.

Zone III.—1. Such effluent shall be free of noticeable floating solids, oil or grease, and substantially free of both suspended solids and sleek.

2. Such effluent shall be sufficiently free of turbidity that it will not cause substantial turbidity in the water of the Delaware River after dispersion in the water of the river.

3. Such effluent shall show a reduction of at least fifty-five (55) per cent of the total suspended solids and a reduction of not less than thirty-five (35) per cent of the bio-chemical oxygen demand. (It is the intent of this requirement to restore the dissolved oxygen content of the river water in this zone to at least fifty (50) per cent saturation. To accomplish this, it may be necessary, in the case of certain wastes, to obtain reduction greater than those required under this item.)

4. Such effluent, if it be discharged within two miles of a public water works intake or within prejudicial influence thereof, shall at all times be effectively treated with a germicide.

5. Such effluent shall be sufficiently free of acids, alkalis, and other toxic or deleterious substances, that it will not create a menace to the public health through the use of the waters of the Delaware River for public water supplies, or render such waters unfit for industrial and other purposes; or cause the water of the Delaware River to be harmful to fish life.

6. Such effluent shall be practically free of substances capable of producing offensive tastes or odors in public water supplies derived from the Delaware River.

Zone IV.—1. Such effluent shall be free of noticeable floating solids, oil, or grease, and substantially free of both suspended solids and sleek.

2. Such effluent shall be sufficiently free of turbidity that it will not cause substantial turbidity in the waters of the Delaware River after dispersion in the water of the river.

3. Such effluent shall show a reduction of at least fifty-five (55) per cent of the total suspended solids and shall be subject to such further treatment as may be needed to prevent a nuisance.

4. Such effluent, if it be discharged within prejudicial influence of a public water works intake, or of recreational areas, or of shell fish grounds, shall at all time be effectively treated with a germicide, except that in the case of recreational area influence,

such treatment need not be provided during the period from October 15th to May 15th of each year.

5. Such effluent shall be sufficiently free of acids, alkalis, and other toxic or deleterious substances that it will not create a menace to the public health through the use of the waters of the Delaware River for public water supplies, or render such waters unfit for commercial fishing, shell fish culture, recreational, industrial or other purposes.

6. Such effluent shall be practically free of substances capable of producing offensive tastes or odors in public water supplies derived from the Delaware River.

Interstate Tributaries

It is further recognized by the signatory States that the quality of the waters of the interstate tributaries of the Delaware River and its aforesaid West Branch are of interstate concern at their points of confluence with the Delaware River and its West Branch. Therefore, it is also agreed that sewage, industrial waste or other artificial polluting matter discharged into, or permitted to flow or to fall into, or be placed in any intrastate tributary of the aforesaid Delaware River, shall be treated to that degree, if any, necessary to maintain the waters of such intrastate tributary immediately above its confluence with the aforesaid Delaware River in a condition at least equal to the clean and sanitary condition of the waters of the Delaware River immediately above the confluence of such tributary.

Standard Methods

Analyses and tests regarding the minimum requirements herein prescribed, shall be determined in accordance with the provisions contained in the American Public Health Association's latest edition on "Standard Methods for the Examination of Water and Sewage."

Future Requirements

The aforesaid requirements as to treatment of sewage, industrial wastes or other artificial polluting matter and as to the sanitary quality of receiving waters are minima. It is the intent and purpose of these requirements to accomplish reasonable and adequate control and correction of pollution. Due to the many variable factors involved, however, and to the impossibility of forecasting future developments with certainty, it may be necessary in the future to impose additional requirements, particularly in Zones II and III.

The minima herein prescribed therefore, shall be considered the first steps toward attaining the objectives sought, and if necessary, may be required to be supplemented in the case that the general application of such minimum requirements do not adequately improve and maintain the sanitary quality of the waters of the Delaware River.

Ratification by:

Interstate Commission on the Delaware River Basin .....May 21, 1938.
State of New Jersey Department of Health .....June 7, 1938.
State of New York Department of Health .....June 17, 1938.
Commonwealth of Pennsylvania Department of Health .....June 23, 1938.
State of Delaware State Board of Health .....June 28, 1938.